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JOURNAL
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VOL. 18 JANUARY, 1926 No. 1

SYMPOSIUM ON "METHODS AND RELATIONS IN EXTENSION WORK IN AGRONOMY"

Leader: O. S. FISHER, Extension Service, U. S. Department of Agriculture, Washington, D. C.

1A. "What is the Most Efficient Organization of Agronomy Extension Work in the College?"
M. S. McDowell, Director Extension Service, Pennsylvania State College

1B. "The Part-Time Extension Specialist in Agronomy"
K. L. Hatch, Director Extension Service, University of Wisconsin

2A. "The Responsibility of the Agronomy Department of the College in Developing Good Seed and Seed Certification"
C. B. Smith, Chief, Cooperative Extension Work, U. S. Department of Agriculture

2B. "Seed Improvement Work as Organized in Montana"
A. J. Ogaard, Extension Agronomist, Montana Agricultural College

3. "Visual Aids in Agronomy" (Illustrated)
L. F. Graber, Professor of Agronomy, University of Wisconsin

4. "A Simple Test for Detecting the Nutrient Needs of the Corn Plant"
G. N. Hoffer, Agent and Pathologist, U. S. Department of Agriculture, and Assistant Botanist, Purdue Agricultural Experiment Station

1A. WHAT IS THE MOST EFFICIENT ORGANIZATION OF AGRONOMY EXTENSION WORK IN THE COLLEGE[1]

M. S. McDowell[2]

The viewpoint from which a problem is considered has a great deal to do with the method to be followed in its solution. It is probably true that there is no "best method" to be applied in all circumstances and under all conditions.

Therefore, we do not wish to be understood as presenting an argument for any particular scheme or form of organization, but as presenting a viewpoint on the subject and giving some of the reasons why the general method followed in at least one state has given satisfactory results.

Let me say here that in all extension work the character of the subject-matter to be taught should be that which the corresponding research division approves. This should apply regardless of the way in which the extension work is organized.

It is desirable that extension specialists be officed with the corresponding teaching and research departments and that there be a friendly working relationship.

The foundation premises which represent the starting point in the development of any scheme of operations may have much to do with the conclusions at which we arrive. What applies to extension specialists in agronomy will apply to specialists in all lines of activity.

It may be well, therefore, to consider some of the functions which a specialist should perform.

If an extension specialist in agronomy, or in any other subject, is one whose time is largely given to meeting requests from farmers or from county agents, to address meetings upon subjects within his realm, and if an itinerary is arranged for him accordingly, it probably matters very little how or where he is fitted into the organization. Of course, in any event, some of his time will be given to such work, but in our opinion the real function of a specialist lies in other directions.

He must furnish the technical information upon which a real extension program must be based; he should have a definite part in the planning of programs involving his subject-matter; he should give supervision to the demonstrations, which means that he should have something to suggest about the form of the demonstrations as well as of the follow-up work necessary to be done; and he must be the judge of what follow-up work is necessary. He should see that proper records of the results are kept so that the demonstrations may be made to speak with a stronger voice. His function is more than simply furnishing technical information. Suggesting methods to be used in furthering the work is also an unescapable part of his duties. It is important that he furnish the inspiration which is essential in making extension work effective in the community. If he can do all these things he will be recognized as the leader in his line of work by the county agents, by the farmers, and by the community in general, and this is the rightful place of the specialist.

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[1] Paper read as a part of the symposium on "Methods and Relations in Extension Work in Agronomy" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] Director of Extension Work, Pennsylvania State College, State College, Pa.

We would not wish to say which is the more important in extension work, the specialist or the county agent, but we have no hesitation in saying that each is essential to the other and that no satisfactory or permanent system of extension can be developed without the specialist.

The specialist and the county agent each have definite functions to perform and each is a necessary part of one system.

With these things in mind, the planning of a state-wide extension program in agronomy, or in any other line of work, and the fitting into it of the various counties and local communities is as large a responsibility, as great a task, and requires as much training and experience as does the development of a research program or a teaching system.

The organization in which the extension activities constitute a single unit and under which the individual in charge of agronomy extension is responsible wholly to the extension service and holds the same relative rank in the institution as the head of a teaching or research department has much to commend it.

Some of the reasons for this view may be presented as follows: The larger the job the better the man who can be obtained to fill it. If extension work is a secondary consideration, it will not appeal to the type of individual we like to see doing extension work. If one may be made to feel that there is a field as large as research or as teaching and that there is freedom of action in the development of that work, better men may be obtained. Freedom in initiative always gives better results.

An individual may be chosen with respect to his adaptability. There are men who are well fitted for research but who are not good teachers or extension workers and vice versa. Under the system of organizing extension activities as such it is possible to select a man with particular reference to his adaptability.

The method makes possible the development of a common program for the county agent, the specialist, and all concerned so that there is no division of effort; and proper direction, coordination, and supervision are more easily exercised. The character of the work should be the basis for naming that work and not the individual worker as such.

The designation, county agent work, is a misnomer. All work in agronomy whether done by the county agent or the specialist should be designated as extension work. All work should be designated as extension work and each part of the organization must contribute its share toward accomplishing the desired result. Neither the specialist nor the county agent can accomplish the most effective results unless their efforts are coordinated into a common program.

In such a scheme of organization, the extension specialist is not second, third, or further down the line in the department and seeking promotion.

Continuity is of more vital importance in extension than in teaching or research. In teaching, a course is carried from the beginning to completion in a semester. In research, a problem is carried usually to a definite stage and complete records make it possible for another, with the necessary technical background and training, to take up the work.

In the case of extension, thorough knowledge of the state and personal acquaintanceship are essential to the most satisfactory service. There is definite and systematic contact with the people and the latter recognize the important part that the specialist plays in the program.

It is our experience that that form of organization in which extension is a unit with direction and responsibility centralized serves the purpose best.

In conclusion, if we may state the proposition in another way, the question of whether one is considering the subject from the viewpoint of the development of the department concerned or from that of the work to be done is a factor to be taken into consideration in the giving of an answer.

Which should be considered, the department or the job to be done?

We believe that service in return for public funds appropriated should be the first consideration and that the form of organization should be that which will give the best account of itself.

1B. THE PART-TIME EXTENSION SPECIALIST IN AGRONOMY[1]

K. L. HATCH[2]

It was my understanding that your chairman desired a discussion of the relative merits of part-time vs. full-time extension specialists in agronomy work and that Director McDowell was to present the case for the full-time worker. While Wisconsin has both full-time and part-time workers in its organization, this discussion will be confined strictly to the part assigned me.

IDEALS IN EXTENSION WORK

The quality of work is governed largely by the ideals of the worker. Who is likely to have the highest ideals? The man who does his own research work and who, fired with the enthusiasm of conquest, carries his own discoveries directly to the field—or the one who must browse around among the achievements of others in order to build up his message?

It is our belief that the worker who does his own research work carries with him the highest ideals and the largest body of accurate knowledge. Again, the part-time extension specialist is, or should be, always up-to-date. He will keep his hearers alive and himself from growing stale by the new things that are continually revealed to him.

STAFF MORALE

The second reason why the work of the part-time specialist is likely to be superior is found in staff morale. Institutional and personal rivalry cannot exist as is likely to be the case in the extension worker who must depend upon others for the material which he uses in his work. Difference of opinion cannot exist—no man will differ with himself—neither will he be jealous of himself. Yet these are often great handicaps to the full-time extension worker.

WHO DOES HIS WORK BEST?

This is the chief debatable point. Granted that the worker has high ability in both research and extension teaching, the part-time specialist, for the reasons already stated, will do his work best. But it is not always easy to find equal research, extension, or teaching ability combined in the same person. Neither is it so easy to find a single worker able to carry on research in several lines of work successfully at the same time. If a choice has to be made as between three men each doing research, teaching, and extension work in a single field and the same three men, the one carrying on three lines of research, another teaching three subjects, while the third takes the results of all three lines to the field through extension work, choice inclines to the former method as the most efficient. It must be granted, however, that personal qualities may be an effectual bar to this arrangement.

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[1] Paper read as a part of the symposium on "Methods and Relations in Extension Work in Agronomy" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] Director of Extension Work, University of Wisconsin, Madison, Wisc.

GETTING THE WORK DONE CHEAPEST

If we are to get the work done at least cost, especially in small institutions or in small departments, necessity may and often does, compel the use of part-time specialists. In small institutions there is little doubt that this is the most economical way. Where funds permit and work demands, the full-time specialist may have his time fully assigned to extension teaching the year round. Under this arrangement it is probable that certain seasons of the year are times of "slack work." On the other hand, the part-time worker has no slack season. His work is so planned that his research, teaching, and extension duties do not interfere, but keep him fully occupied.

DISADVANTAGES

The disadvantages of the part-time plan may be summed up as follows: Such an organization is much more difficult to administer. It is doubtless because of this fact that there is a gradual drift away from the part-time system. The ultimate end of this drift is a separate extension staff with separate administration, a final breaking down of morale, and a re-organization on a plan designed to knit together all the work of the institution, its teaching, its research, and its extension. This has already occurred in several institutions and is likely to occur again.

The other large disadvantage lies in the difficulty in securing men equally capable and enthusiastic in two or three lines of work. Not everyone can do teaching, research, or extension work equally well. Even if such ability exists he may not be equally interested in all these duties. This is the second great disadvantage of the part-time system.

If these disadvantages can be successfully met, then the part-time worker is to be preferred because he creates higher ideals, contributes most to staff morale, does his work better, and does his work with greater economy of time and money.

2A. WHAT IS THE RESPONSIBILITY OF THE AGRONOMY DEPARTMENT OF THE COLLEGE IN DEVELOPING GOOD SEED AND SEED CERTIFICATION[1]

C. B. Smith[2]

"Better Seed" is an extension slogan in a good many states. There were 224,000 demonstrations carried on by the state extension services in 1924 to teach the value of better seed. This was about a fifth of all the demonstrations carried on in 1924 of all kinds. A lot of our extension energy is spent on securing and planting better seed every year, and yet, when I came to look into just how important better seed is to the farmer in dollars and cents, I found very little definite information. I wrote, therefore, to a number of agronomists in the central states to get their estimates of the value to the farmer of improved seeds.

I summarize only a few of the replies received, but sufficient to show the trend and establish the point I desire to make.

Michigan estimates the planting of about 600,000 acres of improved cereal seed, including corn and beans, annually, resulting in an increased income of nearly $2,000,000 to the farmers of that state, while the income resulting from the substitution of Grimm and Hardigan alfalfa for clover has been worth to the farmer over $8,000,000, a total average of about $50 per farm more for every farm in Michigan because of better seed.

Nebraska estimates over 5,650,000 acres of cereals planted to improved seed, with an increased money value of at least $7,825,000 or over $62 per farm, annually. No one knows how much of this gain is offset by farm losses due to unknowingly planting unadapted clover and alfalfa seed from Italy, Peru, and the Argentine.

Ohio estimates that could she but get 50% of her farmers to use better cereal and forage seeds and potatoes the increased income to the farmers would amount to a minimum of $13,000,000 annually, or an average of $57 per farm for every farm in the state.

Iowa gives data showing that in 1924 there were grown over 2,667,000 acres of improved oats alone in that state and that the increase from this acreage was over 11,000,000 bushels. About 46% of the entire oat crop of the state was from station-improved seed.

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[1] Paper read as a part of the symposium on "Methods and Relations in Extension Work in Agronomy" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] Chief, Office of Cooperative Extension Work, U. S. Department of Agriculture, Washington, D. C.

Data similar to the above were obtained from a number of other states and are undoubtedly available in nearly every state. Suffice it to say here, however, that of all matters entering into the production of field crops the item of live, adaptable seed from high-yielding strains is undoubtedly of most importance and, if such seed were placed within the reach of every farmer and he availed himself of it, hundreds of millions of dollars would be added to the wealth of the nation annually. We know of nothing worthier to strive for in the extension field than the securing and placing within the reach of every farmer of such seed.

Better seed may mean adaptable seed, improved strains of seed, clean seed, germinable seed, disease-free seed, disease-resistant varieties, etc. In considering adaptable seed, results of federal and state investigations have shown for example that clover seed of Italian origin fails to produce a crop that will withstand our northern winters. Indeed, I understand it fails in practically every section of the United States, though the amount imported sometimes runs into millions of pounds per annum. When planted alone, it results in an entire loss of time, labor, and land to the farmer. It is here that the federal government should function in such a way as to prevent clover seed of Italian origin being sold, at least in the northern states, and perhaps anywhere else in the United States.

Likewise, it has been found that alfalfa seed from the Argentine, Chile, and southwestern United States will not produce a crop in the northern states which will withstand northern winters. Just how to keep this seed, which is fine in appearance and valuable seed for the southern states, from being mixed with seed of northern origin for planting in the northern states, thus incurring great annual losses to the northern farmer, is a problem for the states and federal government, working together, to solve. This association might well give expression to its views on this matter as a basis for proper education and possibly legislation.

We now come to the consideration of the responsibility of the agronomy department of the colleges in developing good seed. The agricultural colleges are especially concerned in the welfare of farmers.

The agronomy department of the college represents the college in its recommendations to the farmers as regards planting of field crops and the development of the state's crop program. It should be a source of reliable information to any and all farmers of the state. One of its greatest functions in promoting the welfare of the states is probably in seeing that there is within the reach of every farmer a supply of adaptable seed of high quality, and in order that the agronomy department may know what it is doing it must itself test out or supervise the testing of the adaptability of varieties to the different sections of the state. In some cases where no varieties are found suitable to the state, the agronomy department may find it necessary to do breeding work in order to secure such varieties.

Let us suppose that the state needs a disease-resistant wheat, and that the agronomy department has bred up such a wheat. What are the preliminary and ultimate steps that should be taken in getting this wheat into the localities of the state where it is adapted, and within reach of every farmer? First, the college develops a small amount of seed from its breeding plats at its central experiment station. Following this, the agronomy department tests this out in the various regions of the state to learn its adaptability to the different soil types and climatic conditions. When the experimenters have found out the regions to which the seed is adapted, their next step is to multiply it so that a quantity may be obtained for wider distribution. The agronomy department itself should probably grow a sufficient amount of the seed to supply four or five outstanding farmers of the state who can be trusted to plant it first in small field areas and then in larger amounts.

With a substantial amount of seed thus obtained the next step will be its distribution into all the counties of the state where adapted. Here cooperation with the extension forces of the college should be sought. Every county agent of the state concerned in the growing of wheat should be solicited to find three or four farmers in the county who may be trusted with the initial growing of the seed in such county. These farmers thus selected should be encouraged to buy seed from the three or four growers into whose hands the college has placed the seed. If the three or four farmers in each county who grow the seed find it surpasses their own varieties, the county agent should lend his aid in acquainting all the farmers of the county with the virtues of this seed and the sources of supply. If the variety is outstanding, a campaign may be put on the second or third year to see that every farmer in the county is acquainted with the virtue of the seed and sources of seed supply near his own home.

The methods above described are based upon there being a county agent in every county of the state and all of the county agents responding to the suggestion that they select farmers for multiplying a particular strain of wheat. The facts are that some counties are without county agents and that some county agents will fail to function and there will be many farmers in counties without agents who will have heard of the new wheat and want to get a supply of seed. In order to meet this situation, the agronomy department may encourage the formation by wheat seed-growing farmers of a state-wide seed association. This association may or may not pool its seed but constitute an organization to which any farmer in the state may write for seed and learn the name of the farmer nearest to him where such seed is available. In the early stages of the work, the agronomy department itself may send out the list of names of men growing the seed throughout the state.

Now, as to the responsibility of the agronomy department as regards certification of seed. All in our judgment that the agronomy department should do would be to place in the hands of the three or four original farmers multiplying the seed a statement to the effect that the college had furnished such growers with a certain amount of seed. The farmers who sell this seed to others should be the ones that certify the source of their seed and that what they supply has been grown from such seed. If an association of seed growers is formed, then the association might take over the function of certifying the seed of its members. It is not conceived to be the business of the agronomy department to solicit membership in any seed association, to handle orders for the association, or in any way assume responsibility for the business of the seed association which the agronomy department may encourage to be formed. The individual farmers and the seed organization which they may form should stand on their own bottom, so far as certification is concerned. It is an entirely proper activity of the agronomy department to teach seed growers or farmers how to recognize the variety under consideration, ways of harvesting, storing, and marketing the seed, cultural methods for keeping it pure, and like matters. The grower and farmer should be taught these things so that they may know themselves how to do each phase of the work involved.

Where the bulk of seed, as in the case of clover and alfalfa, must necessarily be grown in some other state, the agronomy department should seek to impress seed dealers within the state with the necessity of purchasing only seed adaptable to the state and may openly further the work of such dealers as observe the practice of the purchase and distribution of adaptable seed. If the seed dealers hesitate in this matter, then various farmers' organizations, like the Grange, farm bureau, state seed association, or cooperative elevators, should be encouraged to undertake the work with the guidance of the agronomy department as to sources of seed and varieties to get and distribute.

The main thought I want to leave in this paper is that upon the agronomy department of the college falls the burden and the duty of (1) introducing and developing seeds adapted to the needs of the state; (2) multiplying these seeds in the hands of careful men in each region and county of the state, so that a supply of the improved seed is within reasonable reach of every farmer; (3) putting on a campaign through the extension service to get the variety planted on every farm to which it is adapted; (4) making arrangements with seed dealers or farmers' organizations within the state to bring in only such farm seed for general distribution within the state as the agronomy department recommends; and (5) to assist in developing a state seed association if such association is needed to supply seed to miscellaneous farmers and farmers from outside the state who may want good seed.

The agronomy department must be strong in its research work of breeding and testing out varieties. It must follow up every variety it puts out to see that there are always a few breeders in the state and a few breeders in each county who keep the seed supply pure and true to name. Some good creations of the stations have been confused and lost to the public and varieties have lost their potency because the agronomy department turned the variety loose without keeping their hands on it to direct its destiny. If the research breeding and testing work of the agronomy department in any state is weak, then the word of any seed dealer is as good as the word of the college in advising farmers what to grow and multiply and confusion results. The agronomy department should be in advance of the farmers of the state in testing out promising varieties. With close cooperation between the research and extension workers of the agronomy department and the extension agents in the counties, the agronomy department can easily keep the lead as a source of information and help to the farmers over all outside agencies. The main thing is that the agronomy department be strongly manned, keen in the work, and keep constantly before the public the more certain and higher yields obtained from the better varieties. Good publicity probably adds 20 to 25% to the efficiency of the work.

2B. SEED IMPROVEMENT WORK AS ORGANIZED IN MONTANA[1]

A. J. Ogaard[2]

One of the vital questions confronting agronomists and others interested in farm crops may be stated in two ways, *viz.*, (1) How can the results of the work of the experiment station in the testing and breeding of improved varieties of farm crops be most economically brought into farm practice and be made a definite and considerable factor in crop improvement with consequent influence on farm profits through more economic production? (2) How are farmers to be brought to make greater use of better seed of the best varieties of farm crops for their particular section?

The correct and most practical answer to these questions will, of course, vary with the various sets of affecting conditions in the different states. In this paper we make no pretense of laying down any uniform standard plan. Our primary purpose is to outline a plan worked out, the methods employed, and the results obtained under the conditions of one state, in the hope that the discussion may possibly bring out principles of value to workers in other states.

The crop standardization project is of interest not only from the standpoint of its importance from an economic standpoint, but also because it illustrates the fundamental principles of good extension work in an exceptionally clear and simple manner. In fact the crop standardization project has served to a great degree in popularizing among agents, planned, definite, and purposeful work along other lines.

Before the present plan of crop standardization was worked out and adopted, the "hit and miss" method of recommending crop varieties and of distributing the seed was in operation in Montana. Each substation was singing its own independent solo as to adapted strains and varieties, being very careful to note the yield dfferences to the second decimal place and possibly forgetting some insignificant (?) factor such as shortness of straw. Seed was increased on the stations in a haphazard fashion with no definite standards as to purity. The seed was distributed to individuals, sometimes because they were influential politically or merely because they expressed a desire to obtain some seed. In two or three years the identity of the seed was usually lost. There was an entire lack of centralized policy, coordinated effort, and definite follow-up.

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[1] Paper read as a part of the symposium on "Methods and Relations in Extension Work in Agronomy" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

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In developing what we here designate as the Montana Plan, several fundamental principles were kept in mind, namely, (1) the plan should conform to the policies which must govern the agencies cooperating in the plan; (2) the plan should be based on a careful study of experiences along similar lines in other sections; and (3) the plan should be adapted to the existing conditions and must be simple, practical, and workable, and not be too idealistic for practical operation.

Montana is an empire of vast extent, of comparatively scattered population, and still in the somewhat formative and pioneer stage of agricultural development. It is also pertinent to mention that as extension agronomist, the writer is employed on full state time and is not governed by Smith-Lever regulations. We believe, however, that the plan in practice conforms with the spirit and intent of the Smith-Lever Act. Any seemingly technical violation might very easily be avoided by slight modification of plan and of terms used.

No plan can operate in a house, institution, or organization divided against itself. Therefore, it was deemed very essential to secure effective cooperation among the main agencies involved. Fortunately for the plan, the right attitude has prevailed between the agronomy department and the extension specialist. The agronomy department recognizes the place of the extension specialist as the director of the agronomy extension work. There has always existed a perfect understanding with regard to the responsibility of each branch for various phases of the agronomy work. There have been no petty jealousies and all the workers have worked harmoniously together with the idea of "Service" uppermost. The agronomy department has welcomed suggestions as to improvements or additions to the experimental work, and in turn has been duly consulted by the specialist in determining the extension policy, especially relative to subject-matter. It has been correctly assumed that the final determination as to experimental policy and methods must rest with the station agronomist. The extension specialist has been given the responsibility for the conduct of the extension phase of agronomy.

It is recognized that the details of the extension agronomy work should be finally determined and directed by the extension specialist who ought to be well informed along experimental and research lines, but should also have had extension field experience, preferably as a county agent.

It is also essential that the right relationship exist between the county agent and the specialist. The specialist should be conversant with local conditions and problems and must get the viewpoint of the local worker and avoid making theoretical suggestions which fail in practice. The county agent should regard the agronomy specialist as his point of contact with the agronomy department. In the crop standardization plan we have succeeded in securing the wholehearted cooperation of the various agencies concerned. It is strictly up to the extension specialist, however, to direct the plan so that each agency is kept awake and alert, attending to that part of the job for which it has assumed definite responsibility. The need for thoroughness in extension work cannot be overemphasized.

THE MONTANA PLAN

The crop standardization plan may be logically divided into three distinct phases, namely, (1) obtaining the necessary facts relative to standard adapted varieties, (2) demonstrating the standard varieties, and (3) securing the adoption of the standard varieties and inducing farmers to use good seed.

No single institution or agency can or should take the responsibility for the entire plan. The extension organization must assume definite leadership and secure the cooperation of the other necessary forces. Responsibility for the various phases should be assumed by the agency best fitted to carry out each one. This will eliminate duplication of effort and secure maximum results. The plan has been constructed on a foundation of such facts as these: (1) That the best variety for any particular area is that variety which will yield the most profit for an average of years. (2) That home-grown seed of small grains and corn is as good as, if not superior to, any that can be shipped in from outside, providing proper care has been exercised in its production. (3) That the average farmer will be led to adopt the standard varieties through conviction based on observation of performance on fields in his home locality. (4) That the closer to the farm and to the field of operations that responsibility is assumed, the more efficient and economical the operation of the plan. In other words, state supervision and responsibility should be restricted to those phases where local facilities cannot operate with the desired effectiveness.

OBTAINING THE FACTS

The first and most reliable source from which to obtain the needed facts is the variety test work of neighboring experiment stations. This information is constantly kept up to date and the conclusions based on studies of such information are immediately made available to the agents. In this manner, general recommendations as to varietal adaptation may be made, but in many instances additional local information and substantiation must be secured through variety tests. In the case of small grains, seldom more than five varieties need be tested. At present, we have no experiment station man in charge of cooperative field experiments, but the work is entirely under extension direction. It is our opinion that a full time man working hand in hand with the extension specialist and the county agents would be preferable, if the necessary financial support were available. The specialist recommends the varieties to be tested and assists the county agent in securing dependable seed supplies. The tests are usually on a fairly large scale. Comparative yields are secured either by the farmer in threshing each variety separately or by using the "sample area" plan, and threshing by hand. In the corn work the number of strains are of course much greater, averaging 19 strains last year.

The local variety tests are not only of value from the "fact finding" standpoint, but are also very effective in convincing farmers who are naturally skeptical of imported data or statistics not strictly homegrown.

The specialist is responsible for keeping the agent informed and for planning tests and locating necessary seed supplies. He also must study the results of the local and station tests and in cooperation with the agronomy department, draw conclusions upon which to make recommendations. It is but natural to assume that the experiment station tests are increased or modified through suggestions of the specialist based on field needs and observations.

While the stations are in good position to secure necessary data as to milling and baking qualities of wheat, yet the specialist can greatly assist by lining up samples from cooperators and growers, and thus hasten the obtaining of a dependable basis for recommendation.

While the work of laying the foundation of facts is directed and supervised in a state-wide way, the actual responsibility rests with the local extension organization. Thus, the agronomy department, both station and extension, cooperates with the county extension agent in establishing a firm base upon which to construct the convincing campaign, which is the second step in the crop standardization plan.

DEMONSTRATING AND CONVINCING

It is one thing for leaders to know what ought to be done and quite another thing to convince farmers of its practicability and advisability. What agronomist has not shared the experience of addressing community meetings on the subject of "Good Seed and Adapted

Varieties?" After advising the assemblage of the reasonable increase in yields and profits to be gained by the use of recommended seed and expecting a stampede for information as to available seed sources, one too often finds the county agent compelled to coax one of the more progressive farmers in order to secure his cooperation in giving the variety a trial. Extravagant claims and exaggerations would doubtless arouse more interest, but such methods have no place in a permanent extension plan. It is an undisputable fact that the average farmer must be convinced through observation. Popularizing a practice and making an idea "fashionable" also helps to secure its adoption more readily.

With these points in mind, the Montana Plan calls for a campaign of gradual education and demonstration. Immediate and wholesale conversion of the agricultural populace is out of the question. The enlistment of a few leaders as demonstrators is the first necessary step. The field demonstration is of first importance. Fields of the recommended standard varieties are placed in the various communities of the county and serve as resident testimonials. Through crop tours, reports at community meetings, and newspaper publicity, the results of these field demonstrations are gradually disseminated throughout the community and county. The standard variety is emphasized continuously. It becomes the fashionable thing to plant seed of that variety. If the variety has merit, the average farmer will eventually start growing it as a matter of course, probably never even suspecting that he has been even indirectly influenced by any planned extension work. However, results are more important than credit.

Now as to the various demonstration methods used.

1. *Demonstration fields.*—It is the aim to place supervised fields of the recommended varieties in every community. The "approved" seed fields mentioned later in this paper take care of this feature to a great extent. A large number of unsupervised fields of demonstration value naturally result from the use of seed made available through the seed production phase of the project.

2. *Meetings.*—Meetings are usually overemphasized in extension work. It is especially true that most county agents like to depend on the specialist to come to the county and make the talks. This is not only wasteful, but well nigh impossible in a thinly populated state of immense area. When meetings are deemed advisable, we try to help the agent to present the material himself. One of the greatest helps is for the specialist constantly to keep the agent informed through brief circular letters which may be read and then filed for future reference. New bulletins of interest are called to their atten-

tion. Detailed outlines or even entire talks are often worked up for the county agent's use. Meetings have a place, but it must be recognized that only a limited number of farmers are moved to action through meetings. Meetings addressed by the specialist are of special value in familiarizing the public and even the county agent with the details and objects of the plan and in securing their cooperation and interest. In the crop standardization work, agents tell us that our appearance at a few key points in the county serves not only more thoroughly to inform the agent himself, but also makes the securing of the necessary cooperation of demonstrators and growers a much easier proposition.

As a specialist, it has been my aim to avoid the usual Farmers' Institute or Farmers' Short Course type of meeting because of their insufficient use of a specialist's time. We prefer the Unit Course plan where one subject closely hooked up with the county program of work is taken up and hammered hard. "Few but definite and well advertised meetings" is a good extension slogan.

3. *Illustrative material.*—At meetings various types of illustrative material have been used. In the crop standardization project, charts have been utilized to illustrate the plan and also in presenting variety test results. As yet we have not used slides and movies in the crop project except in the corn and tillage phases. We use local views as much as possible and develop outline talks for the guidance of agents in their use.

4. *Seed exchange days.*—A special type of meeting for this project has proved very effective. Last year 32 communities tried out the seed exchange idea. The feature of these all-day sessions was a traveling seed display furnished by the state office. This was made up of conveniently packed carrying cases containing samples from each of the 72 winning exhibits from Montana at the International Grain and Hay Show, Chicago, and samples from most of the exhibits at the State Utility Seed Show. The county agent furnished samples of the available seed supplies of his county, while the farmers of the community displayed local seed supplies. The exhibits served to arouse genuine interest in the use of good seed which was further intensified through a talk covering the plan and the recommended varieties, usually delivered by the county agent from a furnished outline. We find that these seed exchange days are very effective and much worth while. Several circuits will be organized this coming season.

5. *State and district seed shows.*—While the ordinary county or state fair has only limited value from a crop demonstrational stand-

point, utility seed shows, where hand-picked exhibits are taboo, serve to arouse interest and tend to make the growing of standard varieties more fashionable. In Montana we have local and county seed shows usually in connection with the annual corn shows. The extension organization takes charge of these and their activities are directed to the good of the crop standardization cause. In most classes the entries are limited to registered and approved supplies. The state utility seed show is now on a circuit basis, being held at a different point each year. The exhibits are automatically collected and tested in meeting the requirements for registered and approved seed. No extra expense is involved and money awards are hardly necessary. One of our best shows cost less than $100 in premium money. The public responds to a show where the hand-picked exhibits of professionals are barred. The utility seed show is a demonstration of results achieved.

6. *Grain judging contests.*—In connection with the shows this season we have inaugurated farmers' grain judging contests. The Seed Growers Association offers medals for winners of the district and state contests. All contestants must qualify by giving a list of the standard crop varieties recommended for their district. Local winners compete in the county and gradually progress through the district to the state contest. County agents are enthusiastic about the contests from the standpoint of attracting interest to the crop work.

7. *Crop tours.*—Under Montana conditions, tours are sometimes impracticable. However, two types of tours are being employed. First, the crop demonstration tours where several of the supervised fields of the county are visited. Second, conducted tours of farmers to the nearest experiment station. Usually several counties cooperate and the agronomy department is usually represented. In the first type of tour the specialist seldom finds it the best use of his time to attend. Most of the fields visited are planned demonstrations.

8. *Publicity.*—One of the fundamental weaknesses of our extension project work lies in the ineffective use and often entire lack of proper publicity. One of the best forms of publicity in our crop work has been through the local newspaper. A great many county agents must receive assistance, suggestions, and tips regarding publicity and the right kind of a story. Aside from the regular local stories sent to the papers every week and the items contained in the "County Agent Notes," very good cooperation and results have been obtained through special crop editions of the local paper. The specialist must usually act as the starter and must assist in lining up material, cuts, etc.

Farm journals are a potent factor in agricultural improvement which should be utilized to the fullest extent by extension workers. We should not only use them, but there is an opportunity for improveing them and making them more useful through real cooperation on our part. The first essential is to establish a proper relationship between the extension worker and the editor. Each party, therefore, must believe thoroughly in the work of the other and there should be no place for petty jealousies nor small politics. The relationship should be cordial and frank, each party laying their cards on the table, face up. The editor should be "sold" on extension work and the extension worker should be a believer in the farm paper.

The extension worker can help the farm paper by (1) writing timely articles hooking up the subject with extension work whenever possible; (2) by conducting a question box department like "Seeds and Soils," "I have a piece of land," etc. In many cases these questions can be faked in order to get the material into the paper at a timely period. These service departments of the farm paper are quite popular. (3) Encourage county agents and members of the college and experiment station staff to write special articles on timely subjects. (4) Place the editor in touch with farmers and demonstrators for articles on their experiences. Get your ideas out through the farmers' mouths and pens whenever possible. In other words, have your converts give the testimony. (5) Work up special campaign issues of the paper, contributing articles yourself, writing or outlining preparatory details, and assisting the editor in getting the best pictures possible for illustrating and for cover pages, lining up the best articles by county agents, etc. (6) Every issue of the paper may contain short messages from every extension worker in the state placed under the extension radiogram head. The paper sends out the blanks for each issue and messages are limited to 50 words. Our experience indicates that the farmers read these radiograms, and it is a very good means of keeping the high spots of extension work constantly before the public, an example of the above:

> "Extension Agronomy.—Farmers are being urged to 'Save Seed Corn Early' this year as seasonal conditions so far indicate the possibility of early frost which makes the seed corn situation particularly serious. Seed corn sufficient for two years should be selected as soon as the kernels begin to glaze."

The farm paper helps the extension worker by (1) getting our message across to people in an effective and efficient manner, and by reaching many people not otherwise accessible to the ordinary method of attack. (2) It secures more whole-hearted support through confidence inspired by evidence of cooperation between the extension work and the farm paper. (3) The editor sees us as others see us and can tell us our faults and make suggestions for improvement. (4) It is one step in securing unification of agricultural programs between the extension service and the various outside agencies interested in agricultural improvement.

State-wide publicity through the patent inserts for county papers and through the dailies and county papers direct is sent out by the publicity department. The specialist should always be on the alert for stories which may be called to the attention of the publicity men. The daily is essentially important in keeping those indirectly interested in agriculture informed as to the aims and extent of our work.

Bulletins and serial letters.—Good publicity serves to reach and interest a large number of people much more economically than by personal visits or meetings. The average experiment station bulletin is poorly adapted for putting across subject matter to a farmer. Extension bulletins and circulars which get to the point, which are well illustrated, and which answer the farmers' questions in simple, understandable language are proving better suited for the purpose. But many farmers and business men will not read a bulletin unless their interest has been previously aroused.

Serial letters.—Four years ago one of our county agents made a suggestion which led to the serial letter idea. The specialist summarizes the subject matter and presents the material in a brief, easily read and understood form.

Montana uses a four page form, printing three pages and leaving the first page blank except for the franked head. This page is used for the county agent's printed or mimeographed message which gives local color and a more local application to the general subject matter which we get out. Each page is of the regular letter-head size when folded. We believe that leaving the first page for the county agent's message is desirable as a general letter, for the whole state needs some local explanation to hold it down. We find it best to use these seasonally and divide the subject matter on that basis. For instance, for corn (1) seed and seedbed preparation, sent out in March; (2) cultivation, sent out in May; (3) harvesting, sent out in July; (4) seed selection and show corn, sent out in August.

These letters should be put out with proper regard for display. They should be written in a brief, concise, ready-to-read style. It is well to use plenty of illustrations to make the letter attractive and brief. We print the letters for the agents at cost, and the agents of course get the credit for the letters in their own counties. This is an illustration of the specialist staying in the background, helping the agent to get *his* program across in his county and thus indirectly putting the specialist's program across over the whole state. Our average edition is about 11,000 copies and they are furnished at less than one cent each. We feel that the serial letters are effective and much appreciated by the farmers and the county agents.

Posters.—Posters are not especially adapted to the crop standardization plan until it has progressed sufficiently to insure the production of dependable seed supplies. We are planning on using posters on standard and adapted varieties of farm crops and on the value of home-grown seed this coming season. Posters are valuable as supplementary publicity and are especially effective for the business man.

Signs.—Demonstration signs are advisable after the demonstration begins to demonstrate. The sign should be brief and should be readable from the highway if possible. The most popular method of making up the signs is by stencils, either the old brass type, or better yet, the paper stencils cut by machine.

Pictures.—In all publicity work good pictures count. We have had the best success since taking the time to learn how to take good pictures and thereafter in taking the time to get them by using a tripod, carefully focusing and using the meter when in doubt as to the proper time and shutter opening. The specialist should carry a good camera and obtain pictures in the course of his work. Agents cannot be depended upon to furnish the right kind of pictures.

THE FINAL STEP

Making the adoption easier and more probable.—After a foundation of facts has been constructed and various methods of demonstrating and convincing have been employed, the most important step remains. In average extension work comparatively too much stress has usually been placed on demonstrating the method of practice, and not enough has been done toward making the adoption of the practice easier and more probable on the part of the farmer. Not enough work has been done with the object of overcoming "rural inertia." We must spend more time in overcoming the average farmer's tendency to resist change and in making it easier for the farmer to change his tactics. We hold meetings, issue publicity, use illustrative material, conduct tours, encourage fairs, hold special days and put on campaigns, but too often the actual results obtained are disappointing. Many a farmer is converted to the cause but is continually putting off the change. It is up to us to make him adopt the slogan, "Do it now." In seed work the results of the campaign would be far less noticeable if proper means were not taken to make it easy for the average farmer to obtain good seed.

Definite plans for the production of a sufficient supply of home-grown seed of the standard varieties are essential to the success of the entire project. Before formulating a plan for Montana conditions, we studied the work already done or then in progress in other states and Canada. We found various types of crop improvement associations with varying results. In trying to analyze each case and to arrive at some conclusions regarding the causes for success or failure in each particular instance, the following general deductions were evolved: (1) In too many instances the main activities of the associations appeared to be largely confined to the production of large quantities of pure seed under the *direct* supervision of the state organization. (2) Not enough thought seemed to be given to a proper geographic distribution of the seed fields nor were any definite plans very much in evidence for securing the greatest effect in general seed improvement. In other words, the seed work was not directly nor effectively hooked up with the crop standardization project. (3) There did not seem to be any recognition of a clear cut distinction between seed work for crop standardization purposes and similar activities for nothing but direct individual commercial gain on the part of the grower concerned. It is apparent that some distinction should be made when the work is supported and supervised by extension funds.

As a result of these studies and with our knowledge of Montana conditions, it was determined that the Montana Plan should include the following features: (1) Our first consideration should be to make available in each county dependable seed supplies of the standard varieties. (2) The state work should be confined to making available a limited supply of high grade, home-grown seed as foundation stocks for the use of growers producing quantities of seed under local supervision. (3) The experiment station should assume definite responsibility for the annual production of limited quantities of high quality foundation stocks of all of the standard varieties. (4) Inspection and certification should be restricted to standard varieties. (5) The extension service should supervise the seed certification work directly, insofar as such work is a necessary link in the crop standardization plan. At present the extension agronomist is the secretary of the certifying association. This may be only a temporary arrangement, but control will be retained through establishing a direct working relationship between the extension specialist and the secretary in the event a change is deemed desirable. It is evident that increase of seed by special growers under the control and supervision of the college is an essential in the crop standardization plan. This must be done through a definite plan with a "dollars and cents" appeal, as growers will not cooperate on a purely idealistic, "public benefactor" basis. (6) The certification work should be made self supporting where seed is produced in quantities for outside commercial marketing. While we do not feel that it is desirable nor necessary to handle the certification work necessary for crop standardization in an association separate and distinct from the certification on a strictly commercial basis, we do insist that extension funds, either state or federal, should not be used for pure "service" seed certification work, where the benefits accrue only to the grower concerned. If the extension specialist does any work of this kind, it should be compensated by the association paying for extension clerical work. (7) Extension specialists and county agents should not assume any responsibility for the quality of the seed sold under registered or approved seed tags.

Under the plan now in operation, the agronomy department of the experiment station assumes full responsibility for improving and maintaining the purity of foundation seed stocks of the standard varieties. The station fields are inspected and graded on the basis of seed laboratory tests by the Montana Seed Growers Association. The limited supplies of such seed known as "Elite," are turned over to the extension agronomist who distributes the seed at prices determined by the station agronomist

The Elite seed stocks are placed with the best registered growers in the various parts of the state. Seed produced directly from such seed under the rules and regulations of the Montana Seed Growers Association is known as "Registered Seed, First Generation." Seed supplies in succeeding years are designated as second, third, and fourth generation, and thereafter as registered with no reference to the generation. This plan tends to encourage the registered growers to renew their foundation stocks from time to time.

The field inspection and seed certification work is conducted in the name of a semi-official organization called the Montana Seed Growers Association. The policies of the association are largely determined by the agronomy department. The extension specialist acts in the dual capacity of secretary and "benevolent despot." It is our opinion that the certification work must be in some way or another closely linked up with the extension service, but under no condition would it appear advisable to make any extension worker responsible for the quality of the seed sold under the registry or approved seed tags.

We pass on the fields and the growers submit representative samples of the cleaned seed for use in testing and grading by the Montana Seed Laboratory This representative sample is accompanied by the grower's affidavit as to origin of seed, representativeness of sample, and total yield, as well as an agreement by the grower to settle any complaint on the basis of a decision made by a committee of growers after facts have been submitted on both sides. Further than seeing that the regulations are obeyed, the secretary and the association assume no responsibility.

The number of registered growers is limited and are apportioned among the counties on the basis of interest and needs. At present the inspections are made by members of the agronomy department staff who find this work gives them an excellent means of making contact with the farmers and practical conditions and problems. When the registered work is limited, the inspections are not burdensome.

From the standpoint of commercial inspections, the work may be made strictly self supporting by using trained students or men from the regular staff on leave, paying them entirely from association funds We can justify any direct temporary support given at present only on the basis of organizing the work and keeping it on its feet until it learns to walk.

At the time of the annual conference, the specialist holds individual sessions with each agent, discussing the results of the past year and laying plans for a better and more balanced program for the coming year. At that time the county quota of registered growers is definitely fixed. The agent is then responsible for lining up the required growers. On first thought, most people assume that this hand-picking and limiting of growers would not work out in this country where we are all born free and equal. However, we have had no serious trouble along that line up to this time. By explaining the plan through preliminary meetings and constant publicity, farmers recognize the need for delegating the pure seed job to a few.

The growers plant either Elite or Registered seed on clean land, either summer fallowed, intertilled, or sod land, and make application for inspection before June 1st on regular forms furnished them through the agent. Correspondence is carried on directly between the grower and the association, but copies of all correspondence are sent out to the county agent who maintains a separate file folder for each pure seed field in the county for his information.

The cost at present is very nominal. New members pay a $2 membership fee and $1 annual dues. This covers inspection fees up to

10 acres of any standard variety, with an additional charge of 25 cents for each additional acre. This helps to keep the acreage down to a size where the average farmer can handle it.

New growers receive extra attention from the county agent as it is not to be expected that the average farmer can be developed into a pure seed grower without some education and timely encouragement. This also reduces fatalities at inspection time. Bin inspection and grading is accomplished by having the grower send in a representative sample of his cleaned seed covered by affidavit as to yield and representativeness. Official tags are issued on the basis of the State Seed Laboratory test. All seed sales are reported back to the association by means of sales stubs detached from the official tags. County agents should not be used as registered seed inspectors.

Two grades of registered seed are recognized, No. 1 and No. 2. We have no certified class in small grains.

APPROVED SEED

This class of seed is produced under local extension supervision, for local use only. It is not commercial seed and approved seed tags are not used on seed shipped out of the county. Using the limited supplies of "registered" seed as foundation stocks, the "approved" seed growers produce larger quantities of seed under the supervision of the county agent. In this manner the real goal and objective of the entire crop standardization project is achieved. The farmer finds it comparatively easy to obtain good home-grown seed of the adapted standard varieties. This plan secures more acres of adapted standard crops than could be obtained through scores of meetings and reams of publicity. Approved seed supplies are, in our opinion, the most effective element in the entire plan.

The county agents observe the fields in the same way as they would check up any other field demonstration. They require the grower to send a representative sample of the cleaned seed to the State Seed Laboratory for purity and germination test. On the basis of the field observation and the official test, the agent permits the grower to sell the seed *locally* under the County Approved Seed tag under which the agent specifically throws the responsibility for the supplying of seed coming up to the standard of the representative sample upon the grower himself. We cannot see how this activity can be construed as "commercial service work" on the part of the agent. The organization of local associations would eliminate such objections if any be made.

Our experience has convinced us that the division of labor between state and local agencies as exemplified in the production of registered and approved seed supplies is sound and mighty effective practice.

CORN

The plan is essentially the same for corn as for the small grains, with the exception that we have no registered class as yet. Certified seed corn is grown by a very few selected growers chosen on a statewide basis. These growers cooperate in putting into effect practical corn improvement work on a few adapted proved strains. The commercial seed corn supplies are grown by approved growers working with the county agents.

CONCLUSION

This outlines the main features of the small grain and corn standardization plan as it has been worked out under Montana conditions. To give one an idea of the progress and trend of the work, the high points for the years 1924 and 1925 are shown below.

General trend of crop standardization in Montana, 1924–1925.

		1924	1925
I. Obtaining facts	A. Small grain variety tests	184	66
	B. Corn variety tests	129 (11 var.)	72 (19 var.)
	C. Milling and baking tests	—	106
II. Demonstrating and convincing	D. Supervised fields		
	Small grains	201	467
	Corn	92	107
	E. Crop tours	20	22
	F. Meetings	285	Not reported
	G. Seed exchange	—	29
III. Adoption, making it easier and more probable	H. Registered growers	85	152
	I. Approved growers	293	435

It will be noted that fewer but more thorough variety tests are being carried on. The approved seed phase is still lagging, but this is due to its being the last phase to be developed. In seed production and in the degree of standardization achieved to date, the results have far exceeded our fondest hopes.

3. VISUAL AIDS IN EXTENSION WORK[1]

L. F. GRABER[2]

By far the most effective means of bringing about better agronomic practices is the field demonstration. Here the results of lime, inoculation, fertilizers, varieties, and cultural practices are made visible and impressive. For the "doubting Thomas," seeing is believing. The value of a field demonstration, however, can be greatly reduced if it involves too much detail. A demonstration that is planned to show a dozen different features loses its effectiveness. A simple, clear-cut demonstration, with striking contrasts, that illustrates only one or two things of practical importance, will sell an idea, where a complex trial leads to confusion.

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[1] Summary of a paper read as a part of the symposium on "Methods and Relations in Extension Work in Agronomy" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] Professor of Agronomy, University of Wisconsin, Madison, Wisc.

Extension workers should always bear in mind that there are many who believe in the findings of science without being sold on their application. A new idea in agriculture is never "put across" or "sold" until it is actually in practice on the farm where it is needed. I know a well educated and very successful dairyman in southern Wisconsin who had raised alfalfa, in a small way, with indifferent success for a number of years. He believed in lime, but had never used it. At one of our very striking lime demonstrations he said, "I have always felt that I appreciated the true value of lime, but until to-day I never was sold on it. I am going to have 200 tons ground in my limestone quarry this fall." And he did. In fact, since that demonstration, he has applied to his farm 450 tons of lime and now has over 100 acres of alfalfa. It took this demonstration to sell him the idea of using lime for growing more and better alfalfa.

But there are many forms of extension activity wherein the field demonstration is not possible. This holds particularly true during the winter months at which time the usual large number of crop meetings, farm institutes, conventions, etc., are held. At these meetings information is presented. Nothing adds more to the force of the presentation than illustrative material to help visualize the facts in as far as possible. This illustrative material, in a measure, takes the place of a field demonstration, but is not nearly as satisfactory. It is a means to put the necessary "flavoring" into facts to make them appetizing and eagerly absorbed. In no case should illustrative material, such as slides, charts, enlarged photos, or specimens, be the main feature of a presentation. The speaker himself should be the dominant force and the illustrations should only be utilized to make more impressive a well delivered address, conveying important information along with inspiration.

One example of a visual aid is the chart. The chart, however, loses its main function in extension work when it consists of a mass of figures, tabulations, and statements rather than showing, with very few words and figures, a graphic portrayal of the results to be emphasized. The idea of endeavoring to introduce class room details

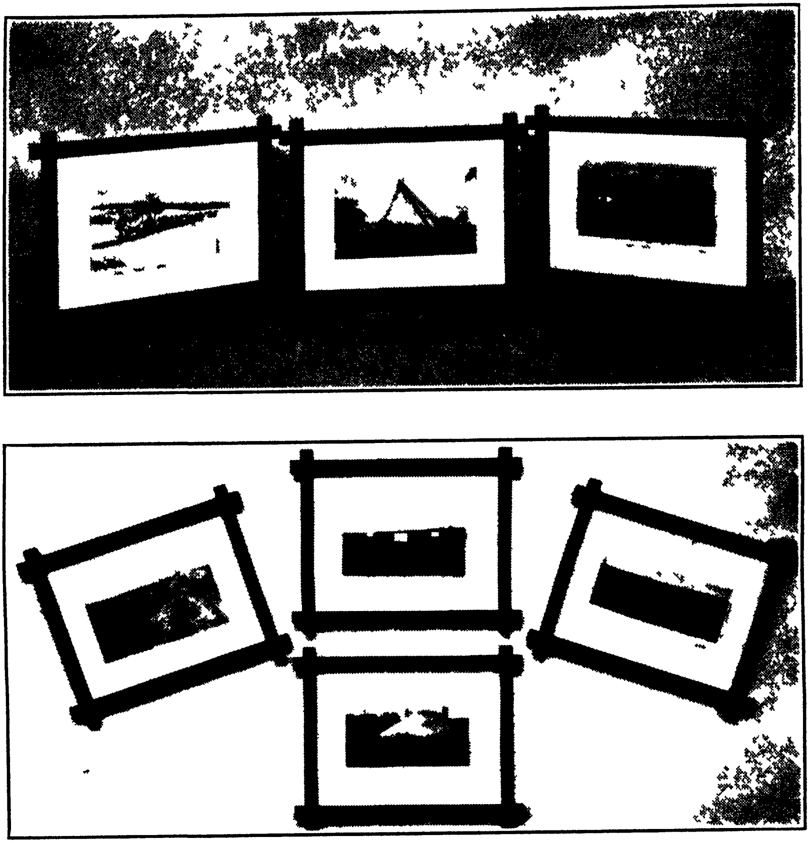

Fig. 1.—Enlarged photographs in frames adapted to table and wall displays.

into extension agronomy is wrong. Farmers are not interested in the details of experimental work. They want the main results, especially that portion which has a practical application. The size of the chart must depend largely upon the size of the audience, but generally speaking the necessity of carrying very large charts is overemphasized. For the average crowd of 100 or 200 people small cardboard charts 15 x 28 inches are very convenient and effective. They prevent the inclusion of too much detail. Only the essential things *can* be presented and this is all that is necessary.

Recently, we have attempted to utilize some of our "dead" photographs in extension work. By "dead" photographs I mean those that have been published in some bulletin or otherwise and, consequently, deemed of no more value. We have these enlarged to a size of about 11 x 16 inches. They are then mounted on heavy cardboard, colored, and properly labeled. We have frames made, without glass cover, in which these views can be easily inserted, giving the appearance of a neatly framed picture. These can be hung on a wall or, by use of a simple standard, can be set up on tables. They aid greatly in periods before and after a meeting is called to order. They stimulate discussion and questions. They can be used very effectively, especially at those meetings that last for two days or more.

Another form of illustrative material is the lantern slide. I think colored lantern slides are, in many respects, more effective than movies—at least they are more convenient. Both may be utilized, but to point out essential cultural practices and to portray field results, the slide is more effective. Again, they should not be the all-important feature of the speaker's address. His presentation of subject material should precede the showing of slides. After the facts have been portrayed by the aid of chart material and specimens, then the slides can be shown to illustrate the things previously discussed. Colored slides are exceedingly effective. It is not well to show too many, especially if some are not good and to the point. To prepare a set of slides requires a great deal of effort on the part of the extension worker himself. He must secure photographs every year and should know the details concerning each view. He should know certain matters of human interest about each scene, for relating these makes the illustrations impressive. It is seldom possible to take a set of slides, prepared by some one else, and make them effective. The lack of intimate knowledge concerning each picture is very apt to show up in the discussion and the hearers may well lose confidence. The extension worker should collect and have made his own slides. He should keep them largely for his own use. If they are loaned out promiscuously, the set is soon ruined and they will not be available when wanted.

4. A SIMPLE TEST FOR DETECTING THE NUTRIENT NEEDS OF CORN PLANTS[1]

(Abstract)

G. N. Hoffer[2]

Corn plants, during the latter part of the growing season, can be used to determine the relative amounts of nitrates and potassium salts available to them during the season. After the ears are well developed on the plants, the presence of reserve nitrates in the stalks can be detected by a simple test of the tissues when the stalk is cut and split open lengthwise. Several drops of a 1% solution of diphenylamine in 75% sulfuric acid applied to the tissues will reveal the presence of nitrates in the juices of the tissues by the development of a blue color. If the test is negative and the leaves and stalk tissues are of a yellow-green color, nitrate starvation is indicated.

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[1] Abstract of paper presented as a part of the symposium on "Methods and Relations in Extension Work in Agronomy" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] Agent and Pathologist, Office of Cereal Investigations, United States Department of Agriculture, and Associate Botanist, Purdue University Agricultural Experiment Station.

The accumulation of iron compounds in the nodal tissues of the plants indicates a lack of potassium, as shown by Hoffer and Trost.[3] The test for iron in these tissues consists of applying an acid 4% solution of potassium thiocyanate to them, and the development of a red color indicates the presence of the iron.

Reserve potassium can be detected in the stalk tissues by cutting a small thin section of the tissue and adding two or three drops of an acid solution of chloride of platinum. Crystals of the double chloride of potassium and platinum will be formed, but it requires a microscope to detect them. In making field tests of the plants, this test is omitted. The determination of the potash requirements is based upon the relative amounts of iron in the nodal tissues. If traces of iron or small quantities only are found, the supply of potassium salts has been adequate, whereas if the iron is abundant the need of potassium is indicated.

The need of phosphates is reflected by retarded or stunted plants in soils acid in reaction. The soil should be sampled and any of the field tests can be used to determine its relative acidity. If the plants are undersized and the climatic conditions were normal during the season, the need of phosphates is indicated. On soils acid in reaction, usually both lime and phosphates are profitably used.

Using these means of determining the nutrient needs, a field survey was conducted during September and October, 1925. Two men were employed and traveled by auto. One man proceeded westward from Vincennes, Indiana, to central Kansas, thence north into Nebraska and east to central Iowa, where, on October 16, a freeze precluded further collections. The other man traveled eastward through southern Indiana into central Ohio, thence to Michigan, and returned through northeastern Indiana to Lafayette.

Representative plants were collected from fields en route, soil samples were taken, and both plants and soils were sent to the laboratory for the tests. This procedure insured a uniformity of testing and put the results on a comparable basis. Nitrate, potassium, and iron tests were made upon the stalk tissues. The size of the stalks was measured. The history and general description of the field were reported by the field men. The fertilizers used during the previous three years were indicated and the system of farming recorded.

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[3] Hoffer, G. N., and Trost, J. F. The accumulation of iron and aluminum compounds in corn plants and its probable relation to root rots. II. *In* Jour. Amer. Soc. of Agron., 15:323-331. 1923.

The outstanding result found in the lâboratory tests was the almost constant presence of reserve potassium salts in the plants from Kansas, Nebraska, and Iowa. Many fields in southern Illinois, Indiana, and Ohio do not carry adequate supplies of available potassium for the corn plant. In the sweet muck soils of Michigan and Indiana this was especially noted

The nitrate content of the plants showed no relation to the reaction of the soil, and neither did the content of reserve potassium when found.

Fields varied markedly in their relative supplies of nutrients, even though the soil samples were of the same type and acidity. Many cases of the effects of continuous corn on the fertility are reflected in the depletion of either nitrates or potassium. The need of phosphates and potash were displayed by plants from many fields in southern Illinois.

The method which is briefly abstracted here will be published in detail by the Purdue University Agricultural Experiment Station, with the cooperation of the Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture. Its use in the field requires but a few minutes, and the fact that it points to specific needs of the corn plants, makes it of great practical value to county agents and growers of corn in general.

A SOIL FERTILITY PROGRAM FOR HAMPSHIRE COUNTY, MASSACHUSETTS[1]

R. A. PAYNE[2]

Economic conditions over which the farmers of Hampshire County, Massachusetts, had no control have made necessary the formulation of a program of soil fertility. When grain and beef began to be shipped from the virgin lands of the central west and could be purchased by the people of this county for less than they could be produced here, farmers adapted themselves to these conditions. Many left their farms here to take up land in the new section. Those who remained found that they could make more money by purchasing grain at a low price than they could by producing their own feed. The more farming they did the worse off they were as the beef and grain they produced brought less than cost of production. Whole milk then became the main source of income on most of our farms. This milk was made largely on purchased grain. So long as grain was cheap, there was more profit to be had by liberal feeding than there was from farm operations, cash crops excepted. These conditions gave rise to the present system of farming which is to depend largely on purchased grain to feed our dairy cattle. There seems to be no prospect of former low grain prices. Home-grown roughages will produce digestible nutrients cheaper than they can be purchased in grain. Since farmers are not feeding maximum amounts of roughage, its production will pay greater profits than it has for several generations. The following is our story of conditions as they exist, the remedies we propose, and the progress we have made in securing the adoption of improved practices.

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[1] Winning program of soil improvement in contest conducted by the Soil Improvement Committee of the National Fertilizer Association, Northern Division. Paper read at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] County Agricultural Agent, Hampshire County, Northampton, Mass.

ANALYSIS OF THE PROBLEM

The 1914 census figures show that there were 2,979 farms in Hampshire County. These farms had 90,083 acres of improved land, an average of 30.2 acres per farm. This improved land was divided in crops as follows:

Crops	Acres	Value
Hay and forage	48,108	$2,123,632
Tobacco	4,610	2,384,516
Potatoes	2,144	1,815,020
Other vegetables, mostly onions	2,841	
Total	57,703	

The remaining 32,380 acres of improved land are largely used as pasture. Livestock is reported on 2,616 farms. Feed purchased on these farms cost $1,420,864, an average of $520 per farm. Practically no hay or forage is shipped out of the county.

The acreage figures show that the bulk of the improved land in the county is devoted to dairy farming. The number of farms reporting livestock indicates that most of the farmers are dairymen. This means that, in the main, a soil fertility program for the county must be adapted to this type of farming. The exception to this is the specialized tobacco and onion area in the Connecticut Valley. In this section, land is high in price and is used almost continuously in tobacco or onions. With the exception of work horses and family cows, no livestock is kept. While about 15% of the total improved land of the county lies in this section, it produces more crop value than the other 85% of the improved land. A soil fertility program applicable to this specialized section of the county would not be applicable to the rest.

The problem of soil fertility on dairy farms can best be shown by referring again to census figures. The make-up of the 48,108 acres in hay and forage crops is shown in Table 1.

TABLE 1.—*Hay and forage crops grawn in Hampshire County.*

Crop	Acres	Tons per acre
Clover and timothy, mixed	17,319	1.4
Other tame grasses	16,710	1.3
Timothy alone	4,597	1.6
Corn for forage	3,040	2.2
Silage crops	2,564	9.9
Small grains, hayed	1,479	1.5
Root crops	1,418	4.6
Wild grasses	544	1.0
Clover alone	241	1.8
Alfalfa	92	2.1

From the figures in Table 1 it would seem that about 37% of the acreage in hay and forage is devoted to mixed clover and timothy. To get such an acreage, either clover would have to last two years after seeding or the fields would have to be seeded once in three years. Neither of these conditions exist. Hence, we believe that this acreage is too high by at least 50%. Yields per acre substantiate this belief. Alfalfa and clover alone give the largest yields per acre but practically none of them is grown. Thus the greater part of the acreage is devoted to acid-resistant crops. This fact, supported by acidity determinations of soils, shows that practically all of the land in the county is far too acid to grow good crops of clover except when large amounts of manure per acre are used. The first part of the soil fertility problem, therefore, is to correct the extreme acidity of the soil on dairy farms.

Figures obtained from 50 representative dairy farmers in all parts of the county last year showed that the larger part of the cows were getting 1 pound of grain for every 3 pounds of milk given. This is liberal feeding of grain. The records also showed that this liberal grain feeding was made necessary because the cows were not getting even a maintenance ration of roughage. Then, too, this roughage was decidedly poor in quality. With purchased feed costing $520 per farm, it would seem that the fertility purchased in this way would increase the fertility of these farms. The low crop yields per acre given in the foregoing table show that this has not been the case except with silage crops. The silage corn is usually manured heavily to the great detriment of the rest of the farm. The second part of the problem, then, is to increase the fertility of the soil.

In view of the fact that the larger part of the improved land of the county is devoted to dairy farming and that the majority of the farmers of the county are dairymen, the county soil fertility program was drawn up to meet conditions on dairy farms. The major problems as stated are to increase the productive capacity of the improved land and to raise the quality of the crops grown After careful study of the methods employed by successful dairy farmers in this and in other sections, the following program of soil fertility was drawn up.

1. Conservation of farm manures.
2. The balancing of manure with acid phosphate
3. The use of nitrogenous fertilizers on the hay crop
4. The use of high-grade mixed fertilizers on cash crops
5 The use of lime where necessary

SELLING THE PROGRAM

The first move in getting the soil fertility program under way was to give publicity to the fact that economic conditions which had decreased the productive capacity of our farms had changed These conditions were discussed at length in articles appearing in the monthly publication of the County Extension Service It was announced that a practical program which would work in the hands of farmers and which would increase farm profits was to be presented

The second step was to arouse further interest on the part of farmers by personal visits and circular letters, urging them to attend meetings at which the problems and the program were to be discussed. These meetings were held throughout the dairy sections. At this time, the agronomy specialist from the state agricultural college presented the facts and the county agent got farmers to agree to try out parts of the program.

The next move was to see that each man who agreed to carry on a demonstration was furnished with complete information regarding procedure. Plats were laid out so that all factors except those under demonstration were as nearly equal as possible.

Signs were posted, calling attention to the fact that certain demonstrations were being conducted on the farm. Much publicity was given in the county paper to the fact that certain men were carrying on these demonstrations. Progress of the demonstrations was noted from time to time. When results were noticeable, demonstration meetings were held to point them out. These meetings took the form of tours when several demonstrations were being conducted in the same neighborhood. In other cases, twilight meetings were held after supper. At these meetings the specialist or the county agent explained the procedure and indicated the results obtained. It was always stated that the result shown was one step in a complete program. The holding of these meetings presented an opportunity to give still further publicity to the fact that steps in the soil fertility program were succeeding in the hands of real farmers

After the crops were harvested and the press of fall work was over, another series of meetings was held. At these gatherings the specialist again went over the program. This time he was able to call upon local men to give "testimony" that various parts of the program worked on their farms as advertised. Then the county agent again signed up demonstrators– this time many more and with greater ease because the farmers had gained confidence. During the next crop season, the same procedure was carried out as regards demonstrations, meetings, and publicity.

RESULTS OBTAINED

When the soil fertility program was proposed, it was expected that it would take several years to get any great number of farmers using the whole of it. For this reason, one or two steps in the program were stressed each year. The use of nitrogenous fertilizers for top-dressing mowings was emphasized during the first two years. Demonstrations showed that nitrogenous fertilizers gave a large increase in the hay crop where there was a good sod to top-dress. Increased yields due to this treatment varied from 1,200 to 1,900 pounds of field-cured hay per acre. The experience of one Farmers' Exchange illustrates the momentum that top-dressing of mowings has gained. The first year that we started work on the soil fertility program, the Exchange handled very little nitrate of soda. Two years later the manager stated that he had difficulty in keeping the amount of nitrate in each car within the fertilizer freight rate. After two years' work, it was found that there was no further need of stressing this part of the program, as it had become common practice.

In many instances it was found that dairy farmers were using from 20 to 30 loads of manure for corn without any fertilizer. This meant that while the corn crop and the following crops for two years were good, the crops on the farm as a whole were not what they should have been. Demonstrations to show the value of acid phosphate to balance manure for corn were conducted with the result that larger crops were grown. The next development was to influence some men to try less manure per acre with acid phosphate for corn so that more manure could be used to keep up the fertility of mowings. These demonstrations showed that this practice was profitable. As a further result, the use of acid phosphate with manure as a top-dressing for mowings has been largely increased. There are towns in the county where acid phosphate was very little used only three years ago and where it is now purchased in carlots. Work is still being stressed on this step of the program, attempting particularly to have farmers use more acid phosphate when they are seeding down.

Potatoes are one of the main cash crops on dairy farms. Tests have been carried on to determine the best formula as well as the proper amount of fertilizer to use on this crop. There have been two decided trends as a result of this work, *viz.*, (1) higher grade fertilizer is being used, a 5–8–7 becoming the standard; and (2) more fertilizer is being used per acre. Not many years ago, about 1,000 pounds of a 4–8–4 or a lower grade fertilizer was thought to be enough. Now the bulk of the acreage is grown on from 1,500 to 2,000 pounds of 5–8–7. This year has not been a good potato season, yet a large number of the growers have produced about 200 bushels per acre, while the county average will probably run about 100 bushels per acre. The increased use of high grade fertilizer has played an important part in making for these better yields. Another result of this liberal use of fertilizers is shown in the better clover crops when the land is seeded down.

Starting in 1924, we began actively to push the use of lime. That year over 100 soil samples were tested by the soiltex method. Practically all of the samples showed the soil to be extremely acid. Eighty-six men were influenced to use lime with the result that 356 tons of lime were purchased. This past year the county agent obtained four dozen soiltex outfits. Some of our men have had from two to six of these outfits during the year to test their own and their neighbors' soil. As a result of this work our figures, which are still incomplete, show that over 900 tons of lime have been used already this year. While some of this lime has been used to start alfalfa, the bulk of it has been used to grow clover.

During the year a few demonstrations were started to show the value of lime for onions. Results have indicated that the use of lime was extremely profitable. Soil samples are being tested at present and, with only a few exceptions, show that the soil is very acid. More demonstrations are being started this year.

With manure conservation, progress has been less striking than with some of the other steps in the program. This is natural as a farmer does not build a manure pit every year. Each year there are requests for manure pit plans. Greater progress has been made, however, in handling methods and in spreading the manure over more acreage. The growing of emergency hay crops, such as soy beans, has been started this year so that the cost of manure made on the farm may be lessened.

The use of one or more of the steps in the soil fertility program means an increased amount of fertility on the farms. Where acid phosphate has been used to balance manure, clover has been increased 100%. Where lime has been used in sufficient amounts, clover not only has been greatly increased, but its productive life has been extended another year. Where acid phosphate and lime have been used with manure, a greater increase in the quantity as well as the quality of the roughage crops has been noted. In the past two years over 200 farmers have carried on demonstrations in soil fertility. Forty-seven meetings attended by over 700 farmers have been held to get the project under way. No record is available of the number of men who have been reached by contact with demonstrations and through articles published in the county paper, yet there is no doubt that many have adopted parts of the program from these sources.

PLANS FOR FUTURE WORK

Work on the soil fertility program to date has been to demonstrate the fact that its separate parts will work in the hands of dairy farmers. This has been accomplished to a marked degree. Confidence has been established. A number of farmers are carrying on the whole program. These farms will be used as demonstrations of the fact that maximum results are obtained only when the whole program is used. They can be used as meeting places where the results of the entire program can be brought out. By giving publicity to what these men are doing, we can get other farmers to seek advice from them. Through these contacts and by means of campaigns, a greater adoption of the practices is assumed.

Little has been said about legumes in this soil fertility program. Yet by carrying out this program, particularly the use of acid phosphate and lime, better legume crops are assured where good farming methods are used. Many dairy farmers who have followed this program have said that they were in a position similar to a certain darkey. He was one of a family of thirteen and never knew that a chicken had anything but a neck till he left home. They never knew that their farms were so well adapted to clover and alfalfa till they began to follow the soil fertility program.

AGRICULTURAL EDUCATION IN FRANCE[1]

H. E. Lefevre[2]

Agricultural education in France is carried on on three plans. At the bottom are the so-called "Practical Schools" and "Demonstration Farms." There is at least one of these schools in every "département," France being divided into about 90 "départements." These schools are attended for two years by boys from 13 to 16 years of age, sons of farmers of a certain section of the country, to whom are taught, in a very practical manner, the farming methods best suited to that particular section. These boys will receive no further education. A few similar schools have been established where girls are trained in the care of the home, etc.

In the second plan are the three so-called "National Schools of Agriculture" or Ecoles Nationales d'Agriculture, one in Grignon, a few miles south of Paris; one in Rennes in Brittany; and one in Montpellier in southern France. Boys spend three years in these schools. The number of students to be admitted every year is strictly limited, and as the number of candidates is always much larger than the number of students admitted, a selective examination is necessary. The school at Grignon is devoted to general crops and animal husbandry, and a remarkable herd of sheep is in existence at the farm of this school. The one at Rennes is more particularly devoted to dairying, and that at Montpellier almost exclusively to viticulture.

If they have passed with success different examinations, boys having attended any one of these schools receive the title of "Ingénieur Agricole" or Engineer of Agriculture.

In the higher plan, at the summit of agricultural education in France, is the National Institute of Agronomy, or the Institut National Agronomique, in Paris. It should be noted that no agricultural science is taught in French universities, and consequently no university degree, such as the doctor's degree or others, is given on subjects related to agriculture. Much stricter still than for the

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[1] Summary of an address made at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] American representative of the French Society of Agronomists.

National Schools, a selective examination is passed before entering the Institute of Agronomy. Though not necessary, candidates generally pass this examination after they have a bachelor's degree.

Boys spend two years at the Institute and if they pass successfully a series of examinations they receive the title of Ingénieur Agronome. They can do post-graduate work at the Institute for one or two years.

The most striking feature about higher French education in agriculture as in other branches is the care with which too early specialization is avoided. At the Institute of Agronomy there is no specialization before post-graduate work. The object is to provide every student with a very sound scientific education, varying from higher mathematics to animal husbandry and from political economy to meteorology, the teaching in every science bearing on the essentials and methods rather than going into the details, this latter being left for the specialist The faculties of understanding and criticism on the one side, the ability of the student to adapt himself later to various conditions and types of work, on the other side, are particularly aimed at

Another noticeable difference between French and American education is the very small number of students admitted every year to the Institute of Agronomy, about 80, as compared with the number of boys and girls attending American colleges of agriculture. Since the war, girls may be admitted to the Institute, but only a very few have availed themselves of this privilege This is probably a necessary result of the difference between the social conditions existing in Europe and in this country

It would be very desirable and profitable for both the American and French nations if more careful attention were devoted by each of them to the study of the other's institutions, methods, and habits. A friend of the writer is at present preparing for an American degree in one of the best colleges in the East. It is the feeling of the writer that other French agronomists should come and work for some time at least in American institutions, though the present financial crisis in France and the low rate of exchange are undoubtedly a very serious difficulty. Likewise, it would probably be worth while for some Americans to go to the French Institute of Agronomy for post-graduate work, for instance, not just to give it the "once over," but to become thoroughly acquainted with French methods of work and habits of thought.

RELATION OF THE DEVELOPMENT OF THE WHEAT SPIKE TO ENVIRONMENTAL FACTORS[1]

T. A. Kiesselbach and H. B. Sprague[2]

Since all of the grain of wheat is borne in the spike, it was thought of interest to determine the relation of spike development to cultural and soil conditions. Grain yields per acre are necessarily expressions, in mass, of the three plant factors: (1) Number of spikes per acre, (2) Number of grains per spike, and (3) Average kernel weight. The investigation at hand supplies information concerning (1) the early developmental phases of the spike and (2) mature spike variations resulting as environmental effects.

HISTORICAL

Although the heritable morphological differences in the spike characters of various wheat varieties are rather well understood, the effect of environmental factors upon the spike characters within a single variety has heretofore been studied directly only to a very limited extent.

Grantham (3)[3] worked on the tillering of winter wheat and Salmon (8) noted the effects of unfavorable weather upon sterility. Grantham and Graff (4), using 25 culms each as representative samples, studied 188 different varieties with regard to occurrence of sterile spikelets. Johnson (5) studied floret sterility of wheats in the southwest as affected by fungous diseases. Arny and Garber (1) made correlation studies between different characters of the wheat plant for a period of four years, but did not show specifically how any of these would be affected by various environmental conditions. Clark, Martin, and Ball (2) have developed a concise classification of American wheat varieties and have described their chief morphological and physiological characteristics. Percival (7) describes the structure and development of the wheat plant mostly under normal conditions. Investigations by the authors on normal development of the spike have largely confirmed the description given by Percival, except that the period required for the later stages of development is shorter in our Nebraska climate than in England. Kiesselbach (6) has indicated the position of the developing spike of winter wheat at different dates in the spring in connection with grazing injury.

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[2] Agronomist at the Nebraska Experiment Station, and formerly graduate assistant at the Nebraska Experiment Station and now Assistant Agronomist at the New Jersey Experiment Station, respectively.

[3] Reference by number is to "Literature Cited," p. 60.

PROGRESSIVE NORMAL DEVELOPMENT OF THE WINTER WHEAT SPIKE

Before discussing the comparative effects of variable factors, it may be of interest to trace the growth of the spike under normal conditions. The optimum seeding date for winter wheat at the Nebraska Experiment Station at Lincoln, Nebraska, occurs during the week following September 22. Fall growth is commonly limited to the two succeeding months. The plant remains essentially dormant during the next three months of December, January, and February, because of low temperatures. Occasionally, slight growth may be resumed during brief periods of mild winter weather. Spring growth is seldom initiated until the warmer weather of early March.

The time, manner, and rate of spike development of the extensively grown Turkey winter wheat may be illustrated for eastern Nebraska conditions by observations made in connection with the 1921 crop. This was a favorable and rather typical wheat year except that the development and maturity was advanced about 5 days earlier than the average. The wheat was sown in the usual farm manner by drilling 5 pecks per acre in rows 7 inches apart.

FALL GROWTH

The fall growth consists mainly of crown, roots, and basal leaves. The culms both of main stem and tillers remain very short, only the lower internode by which the crown is raised is elongated. There was no evidence of differentiation of spikes in the fall, each potential culm being terminated by a vegetative growing point from which leaves were still being formed

SPRING GROWTH

The spring growth may be traced periodically by means of Fig. 1. The development of the spike is very closely associated with that of the culm. Fig. 1, A, is a diagrammatic drawing of a longi-section of a single culm on March 15, 1921, shortly after growth was resumed in the spring. The latent tiller buds at the basal nodes and the smooth growing tip which is to become the spike are evident.

The culm itself has here grown approximately one-third inch in length and its apex is one-half inch below the soil surface. The leaves of the main culm have now all been differentiated. This ordinarily includes approximately four temporary basal leaves arising from the crown and four or five stem leaves. Tillers which develop have their independent basal and stem leaves that correspond in general with those of the main culm. The growing point at this stage consists of undifferentiated meristematic tissue. It is shown diagrammatically somewhat more enlarged in Fig. 1, B.

Fig. 1, C, shows the spike on April 1, indicating an increase in size and the first evidence of spikelets becoming differentiated. By April 20 (Fig. 1, D), the total number of spikelets may be definitely counted. By April 30 (Fig. 1, E), the spikelets have differentiated so that flowers may be distinguished in the spikelet, Fig. 1, F. The median spikelets have passed those at either end of the spike in their stage of development by May 6 (Fig. 1, G), and eight or nine flowers may be counted per spikelet, Fig. 1, H. Only the lower flowers in each spikelet fully develop while the upper ones remain rudimentary.

By May 15 the spike has reached 10 inches above the ground and is one-half inch in length, Fig. 1, I. Only the lower two flowers of the spikelet have developed, as shown in Fig. 1, J. The spike appears normally developed except that it lacks the size and robustness acquired by the time of emergence about June 1. This is followed by fertilization, and maturity is reached in an additional 30 days.

Since wheat matured five days earlier than normal in 1921, the year in which the wheat shown in Fig. 1 was grown, the development indicated for these dates will usually be somewhat later in other seasons. A diagrammatic drawing of a typical wheat plant showing the position of spikes on the main culm and stools May 1, 1922, is given in Fig. 2.

The date of planting also has a significant effect on the development of the plant as is shown in Table 1. Figs. 3 and 4 illustrate the differences in plant development from different dates of seeding at the dates indicated.

EFFECT OF VARIABLE FACTORS UPON SPIKE DEVELOPMENT

EXPERIMENTAL PROCEDURE

The comparative study of variable environmental conditions was made entirely with regard to mature wheat. These investigations were designed to determine the effects of variations in some of the more important limiting environmental factors occurring in this region, and as far as possible, to limit the conditions studied in each case to a single factor. The effect of different dates of planting, different rates of planting, severe spring pasturing, good and poor locations in the same field, and soil moistures are the conditions included in these studies.

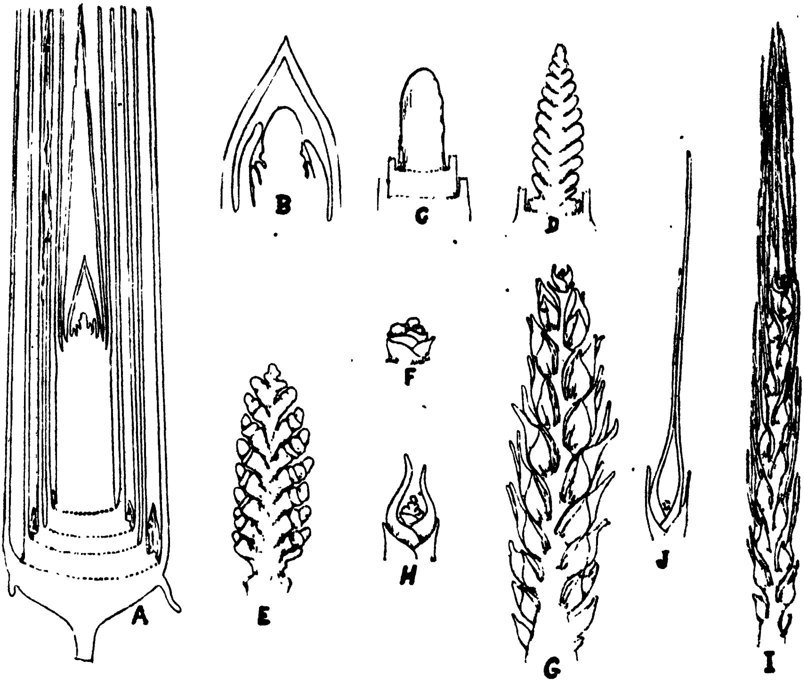

FIG. 1.—Semi-diagrammatic drawings showing the progressive development of the winter wheat spike, 1921.

A, Single culm on March 15, showing crown, basal leaves, tiller buds, and culm surmounted by apical growing tip and main culm leaves. The top of drawing indicates surface of ground. B, Growing tip on March 15 at the same stage as preceding, x 50. C, Growing tip on April 1, showing transformation into spike with first suggestion of spikelet formation, x 50. D, spike on April 20, x 15. E, Spike on April 30, x 15. F, Spikelet from E. G, Spike on May 6, x 8. H, Spikelet from G. I, Spike on May 15, x 3. J, Spikelet from I.

Wheat was harvested from the crops of both 1921 and 1922 for all studies, except the soil moisture test which was made in the greenhouse in 1922 only. Samples for the study of wheat from good and poor locations were obtained from fields on farms within a radius of 10 miles north and east of Lincoln. The samples for studies of the effect of different dates of planting were obtained from experimental fields at the Experiment Station. Wheat for the studies concerning the effect of pasturing and rate of planting was obtained from field plats at the agronomy farm 3 miles northeast of Lincoln, With the exception of the rate of planting study, all samples were from fields sown at a normal rate of 5 pecks per acre with a standard press drill. Fairly normal growth conditions prevailed both years as indicated by average Turkey wheat yields at the Experiment Station

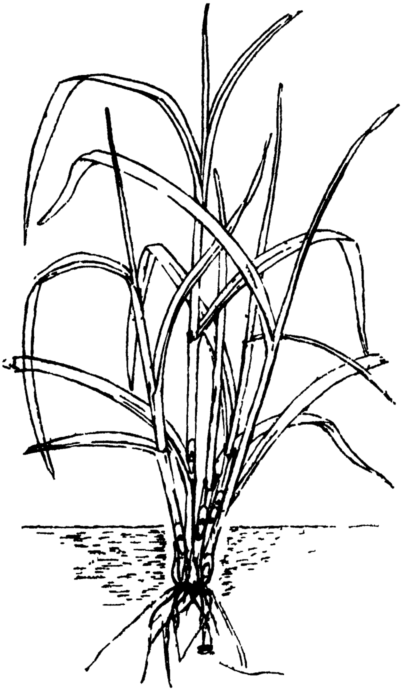

FIG. 2.—Diagrammatic drawing of typical Turkey winter wheat plant on May 1, 1922, growing under normal field conditions, showing location of its spikes with reference to the soil surface. (From Nebraska Agricultural Experiment Station Research Bulletin No. 31.)

of 37 and 31 bushels per acre for 1921 and 1922, respectively, compared with 34 bushels as a 22 year average.

METHOD OF OBTAINING SAMPLES AND DATA

In making these studies, the first consideration was the obtaining of a representative sample of wheat in the field for each condition. After preliminary trials, the following procedure was adopted. As soon as the grain was ripe, ten 1-foot sections in the drill row were measured at random and the plants in them carefully pulled out by the roots. The ten sections, tied together and labeled, constitued a sample to represent that condition and were taken to the laboratory for further study. These samples varied in size but as a whole averaged around 300 culms each. In the laboratory the number of plants was counted and the culms cut off at the former ground level. Each culm and spike was then measured on a wide table covered with cloth ruled in inches and tenths of inches. Culm length was taken

TABLE 1.—*Progressive development of the wheat spike in 1923 in relation to seeding date.*

Sept. 22 to Oct. 1 is the normal seeding period for winter wheat and March 30 for spring wheat in this locality.

Plant character	Date of seeding Turkey winter wheat (Nebr. No. 60) Sept. 16	Sept. 22	Oct. 1	Oct. 16	Oct. 30	Nov. 20	Feb. 15	Mar. 9	Mar. 25	Spring wheat Mar. 9	Mar. 29
			Development by May 18								
Plant height, in	22	21	20	18	17	16	15	11	8		12
Spike height, in	6	5.5	4.2	3.5	3	1.7	.7	0	0	0	0
Spike length, mm	9	8	7	6	4	2	1	—	—	—	—
No. culm leaves out	4	4	4	4	3	3	3	2	2	3	3
			Development by May 23								
Plant height, in	31	29	26	25	23	20	16	14	11	20	18
Spike height, in	11.5	11.7	9.2	8.5	6.2	5.5	2.2	.2	0	4.2	1.7
Spike length, mm	24	28	22	13	6	7	3	1.5	.5	7.0	2.5
No. culm leaves out	4	5	4	4	4	4	3	3	2	3	3
			Development by May 31								
Plant height, in	34	36	35	31	30	29	23	19	14	30	29
Spike height, in	20	22	19	16	13	11	6.5	2.5	0	10.5	10
Spike length, mm	82	78	72	50	50	21	13	3	1.0	13	14
No. culm leaves out	4	4	4	4	4	4	4	3	2	4	4
			Development by June 6								
Plant height, in	40	41	38	38	36	35	31	21	19	34	34
Spike height, in	30	33	31	29	23	21	16	7	0	17	17
Spike length, mm	100	88	87	92	86	88	70	9	2	83	81
No. culm leaves out	4	4	4	4	4	4	4	4	4	4	4
			Development by June 15								
Plant height, in	42	41	42	43	40	42	41	33	27	44	42
Spike height, in	38	37	39	40	35	33	33	16	0	41	43
Spike length, mm	100	90	89	95	94	96	100	35	1	94	95
No. culm leaves out	4	4	4	4	4	4	4	4	2	4	4
			Miscellaneous notes								
Date of fertilization	6–8	6–8	6–8	6–10	6–11	6–11	6–15	6–22	—	6–9	6–10
Date ripe	7–7	7–7	7–7	7–8	7–8	7–10	7–14	7–17	—	7–10	7–10
Yield, grain per acre, bu	21.8	23.7	25.3	21.1	18.4	18.5	12.4	10.3	0	18.4	21.6

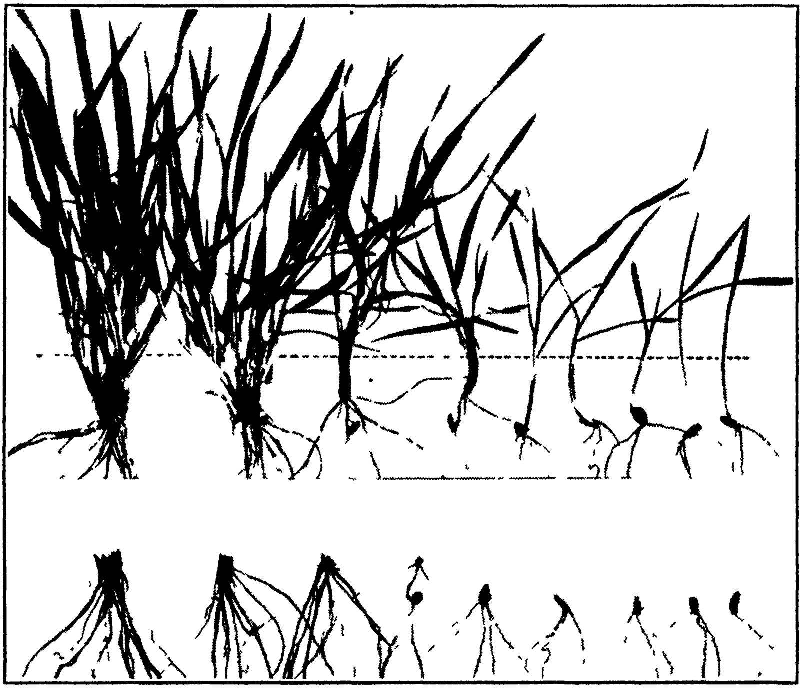

FIG. 3.—Representative Turkey winter wheat plants from nine different dates of seeding, all photographed April 12, 1922. The top row shows whole plants. The bottom row shows plants with leaves stripped off to expose the culms Numbering from left to right: No. 1 was planted Sept. 16, No 2, Sept. 22, No. 3, Oct. 1; No. 4, Oct. 16; No. 5, Oct 30, No. 6, Nov 20, No. 7, Feb. 18; No. 8, Mar. 11; and No. 9, Mar. 24.

The wheat planted September 16 was 7 inches high. The dotted line represents the ground level. Spikes are being formed on the three earliest plantings, an inch below the soil surface.

to be from the ground level to the base of the lowest spikelet on the spike. Spike length was measured from the base of the lowest spikelet to the tip of the flowering glumes on the terminal spikelet but did not include the awns. After measuring spike and culm length, the number of fertile spikelets, the number of sterile spikelets at both the base and the tip of the spike, and the number of grains per spike were counted.

When measurements and counts had been made and the samples were air-dry, they were threshed on a small nursery thresher. Weights were taken of the entire sample and of the grain obtained, the differ-

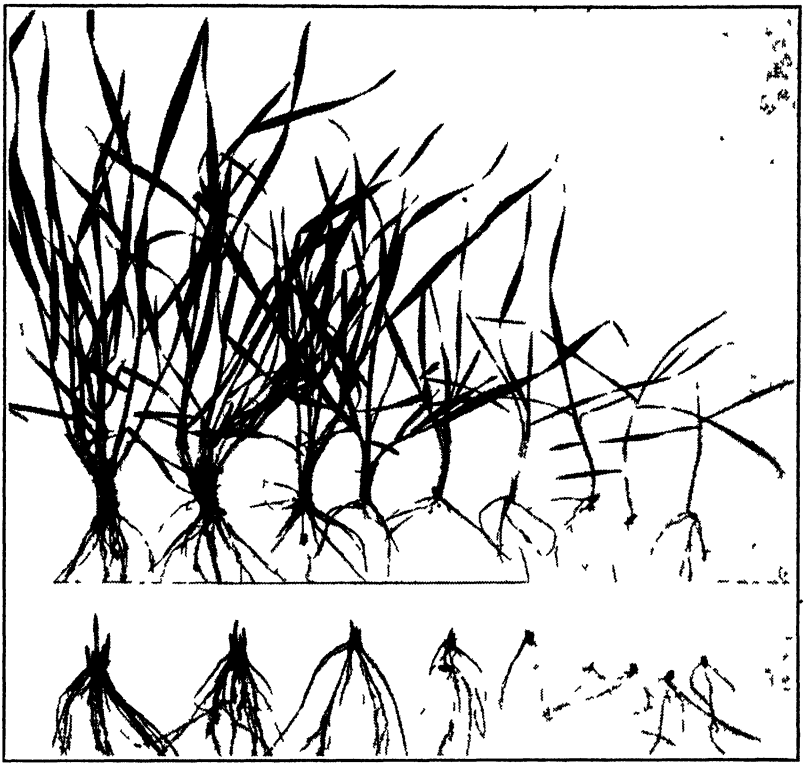

FIG 4 — Representative Turkey winter wheat plants from nine different dates of seeding, all photographed April 25, 1922

The top row shows whole plants The bottom row shows plants with leaves stripped off to expose the heads Numbering from left to right No 1 was planted Sept 16, No 2, Sept 22, No 3, Oct 1, No 4, Oct 16, No. 5, Oct 30, No 6, Nov 20, No 7, Feb 18, No 8, March 11, and No 9, March 24

The wheat planted Sept 16 was 11 inches high Spikes bearing spikelets have been differentiated in the four earliest plantings

ence being taken as the weight of the straw The grain yields shown in Table 2 as bushels per acre were calculated from the grain weight of each bundle With these data at hand it was of interest to obtain expression of these in other terms From the number of plants and the number of spikes per 10 feet of drill row, the number of spikes per plant was calculated The total number of spikelets was obtained by adding the number of sterile and fertile spikelets. The density of the spike was expressed in terms of spikelets per inch of spike. To show difference in flower development of the fertile spikelets, the total number of grains per spike was divided by the number of fertile spikelets, giving the average number of grains per fertile spikelet. The percentage of fertile spikelets and the ratio of grain to straw was also calculated. The actual measurements and counts are averaged for the 2 years 1921 and 1922 in Table 2 and the percentage relative results are calculated in Table 3.

RELATION OF TIME OF SEEDING TO SPIKE DEVELOPMENT

Turkey winter wheat (Nebraska No. 60) was seeded Sept. 16, Sept. 22, Oct. 1, and Feb. 15. Java spring wheat was grown comparably by seeding March 8. For these five seeding dates the grain yields were 26.9, 27.5, 24.6, 11.5, and 9.7 bushels per acre, respectively. Correspondingly, the number of spikes averaged 349, 345, 314, 189, and 213, respectively, per 10 feet of drill row, and 2.5, 2.4, 2.2, 1.3, and 1.4 per plant. The spike lengths were 2.6, 2.6, 2.8, 3.0, and 2.9 inches; the total number of spikelets per spike was 14.7, 14.6, 15.4, 15.2, and 15.6; the number of fertile spikelets per spike was 10.8, 10.8, 11.7, 11.9, and 10.8; the number of sterile spikelets at the spike base was 3.5, 3.3, 3.3, 3.1, and 2.7; the number of sterile spikelets at the spike tip was 0.5, 0.5, 0.3, 0.3, and 1.1; the number of grains per spike was 19.1, 19.2, 20.7, 20.7 and 17.6; and the average kernel weights were 0.024, 0.025, 0.023, 0.017, and 0.016 grams, respectively.

These data indicate no striking differences as to yield or other characters for the first three planting dates, all of which occurred at a relatively favorable time. Planting entirely out of season, however, as on February 15, reduced the grain yield per acre to 11.5 bushels compared with 27.5 bushels as the maximum yield obtained from Sept. 22 seeding. This was brought about largely by a reduction of 48% in the number of spikes due to difference in stooling and to a reduction of 29% in average kernel weight. The spike length and number of grains per spike were actually 15.0 and 8% greater, respectively, for the February seeding.

Spring wheat sown at the normal date, March 8, corresponds in a measure with the winter wheat seeded on Feb. 15. The yield was 1.8 bushels less, due chiefly to a difference of 16% in number of grains per spike and 4% in average kernel weight. Spike length was nearly the same, but 30.8% of the spikelets were sterile on spring wheat compared with 22% on the spring-sown winter wheat. Tillering was 8% higher for the spring wheat.

RELATION OF SEEDING RATE TO SPIKE DEVELOPMENT

When Turkey winter wheat (Nebraska 60) was seeded at the three rates of 3, 5, and 8 pecks per acre, the respective two-year average yields were 25.1, 26.2, and 23.0 bushels per acre. In the order of the 3-, 5-, and 8-peck seedings the number of plants per 10 feet of drill row averaged 94, 146, and 229; the number of spikes averaged 325, 395, and 412 per 10 feet of drill row, and 3.5, 2.7, and 1.8 spikes per plant; the spike lengths were 2.3, 2 2, 2.1 inches; the total number of spikelets per spike was 14.2, 13.2, and 12.6; the number of fertile spikelets per spike was 10, 9.1, and 8.3; the number of sterile spikelets at the spike tip was 0.18, 0.23, and 0.20; the number of sterile spikelets at the spike base was 4.0, 3.9, and 4.1; the number of grains per spike was 17.1, 15.9, and 14.2; and the average kernel weights were 0.027, 0.024, and 0 023 grams, respectively.

Grain yield was the highest, 26 2 bushels, on the normal 5-peck rate of planting, although the tillering and number of spikes was intermediate between that of the 3- and 8-peck rates. The spikes of the 5-peck rate were intermediate in length and the number of fertile and total spikelets and grains per spike showed similar relation to the other rates. Average kernel weight was 4% less on the 8-peck rate than on the 5-peck rate and the number of grains per spike was 11% less. These factors together more than offset the 4% increase in number of spikes per 10 feet of drill row so that yield was reduced 12%. The 4% reduction in yield is accounted for in the case of the 3-peck rate by the fewer number of spikes per 10 feet of drill row, 28% that of the 5-peck rate, which is, however, partly compensated for by an increase of 10% average kernel weight and 7% in grains per spike

EFFECT OF SPRING PASTURING UPON SPIKE DEVELOPMENT

The effect of severe spring pasturing on spike development was determined for Turkey winter wheat (Nebraska No. 60) grown on the agronomy farm. The wheat was kept closely cropped until April 27 and April 25 of the years 1921 and 1922, respectively. Unpastured wheat averaged 12 inches high on these dates. The pasturing was so long continued that some of the spikes growing on main culms were grazed off, causing a higher proportion of stools to develop.

Comparing severely spring pastured with unpastured Turkey winter wheat, the former yielded 15.5 bushels per acre compared

TABLE 2.—*Relation of spike development of wheat to various environmental factors, averages for 1921 and 1922 crops.*

Condition of growth and variety	Plants per 10 feet of drill row	No. spikes per		Length in inches		No. of spikelets				Per inch of spike	Percentage fertile spikelets	Grains per		Ave. kernel weight in grams	Yield per acre[c]		Ratio grain to straw
		10-ft. drill row	Plant	Culm	Spike	Total per spike	Fertile per spike	Sterile at				Spike	Fertile spikelet		Grain bushels	Straw pounds	
								Spike base	Spike tip								
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Dates of seeding																	
Sept. 16, Turkey	137	349	2.5	26.4	2.6	14.70	10.76	3.46	.48	5.65	73.2	19.12	1.78	.024	26.9	2846	.57
Sept. 22, Turkey	141	345	2.4	27.3	2.6	14.61	10.80	3.33	.48	5.62	73.9	19.15	1.77	.025	27.5	2839	.58
Oct. 1, Turkey	141	314	2.2	27.4	2.8	15.36	11.70	3.33	.33	5.49	76.2	20.68	1.77	.023	24.6	2740	.54
Feb. 15, Turkey	143	189	1.3	22.4	3.0	15.22	11.87	3.09	.26	5.07	78.0	20.70	1.74	.017	11.5	1547	.45
Mar. 8, Java Spring	154	213	1.4	24.9	2.9	15.58	10.78	2.73	1.07	5.37	69.2	17.55	1.63	.016	9.7	1607	.36
Rates of seeding[a]																	
3 pecks	94	325	3.5	28.7	2.3	14.15	9.95	4.02	.18	6.15	70.3	17.08	1.72	.027	25.1	2709	.56
5 pecks	146	395	2.7	27.5	2.2	13.22	9.11	3.88	.23	6.00	68.9	15.93	1.75	.024	26.2	3030	.52
8 pecks	229	412	1.8	26.7	2.1	12.61	8.28	4.13	.20	6.00	65.7	14.17	1.71	.023	23.0	2823	.49
Pasturing[a]																	
Pastured	135	292	2.2	22.5	2.4	14.52	9.64	3.89	.49	6.05	66.3	16.04	1.66	.019	15.5	1830	.51
Not pastured	135	365	2.7	30.0	2.4	14.64	10.40	3.89	.34	6.10	71.0	18.43	1.77	.024	27.0	3152	.51
Soil fertility[a]																	
Fertile location	131	429	3.3	31.8	2.4	15.26	10.70	4.37	.19	6.36	70.1	18.74	1.75	.024	32.2	3766	.51
Infertile location	120	234	2.0	20.9	2.1	13.47	9.38	3.93	.16	6.41	69.6	14.20	1.51	.025	14.4	1395	.62
Soil moisture[b]																	
35% soil saturation	—	—	1.6	26.9	3.5	17.29	12.35	4.12	.78	4.94	71.4	21.89	1.77	.033	26.6	3184	.50
45% soil saturation	—	—	2.1	30.1	3.4	18.23	11.79	5.06	1.38	5.36	64.7	20.35	1.73	.033	33.9	4245	.48
70% soil saturation	—	—	2.5	34.5	3.5	20.25	13.20	5.47	1.58	5.79	65.2	22.87	1.73	.030	41.1	5629	.44

[a]Turkey winter wheat. [b]Java spring wheat. [c]Acre yields are computed on the area basis.

TABLE 3.—*Relative effects of difference in environmental factors upon the spike development of wheat, averages for 1921 and 1922, expressed in percentage.*

These data are computed from those in Table 3.

Condition of growth and variety	Plants per 10 feet of drill row	No. spikes per		Length in inches		No. of spikelets					Percentage fertile spikelets	Grains per		Ave. kernel weight	Yield per acre		Ratio: grain to straw
		10-ft. drill row	Plant	Culm	Spike	Total per spike	Fertile per spike	Sterile at Spike base	Sterile at Spike tip	Per inch of spike		Spike	Fertile spikelet		Grain	Straw	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Dates of seeding																	
Sept. 16, Turkey	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Sept. 22, Turkey	103	99	96	103	100	99	101	96	100	99	101	100	100	104	102	100	102
Oct. 1, Turkey	103	90	84	104	108	104	109	96	69	97	104	108	100	96	91	96	95
Feb. 15, Turkey	104	54	52	85	115	104	110	89	54	90	106	108	98	71	43	54	79
Mar. 8, Java spring	112	61	56	94	112	106	100	79	223	95	95	92	92	67	36	56	63
Rates of seeding[a]																	
3 pecks	64	82	130	104	105	107	109	104	78	103	102	107	98	110	96	89	108
5 pecks	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
8 pecks	157	104	67	97	96	95	91	106	87	100	95	89	98	96	88	93	94
Pasturing[a]																	
Pastured	100	80	81	75	100	99	93	100	144	99	96	87	94	79	57	58	100
Not pastured	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Soil fertility[a]																	
Fertile location	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Infertile location	92	55	61	66	88	88	88	90	84	101	96	76	86	104	45	37	122
Soil moisture[b]																	
35% soil saturation	—	—	64	78	100	85	94	75	49	85	110	96	102	110	65	56	114
45% soil saturation	—	—	84	87	97	90	89	93	87	93	99	89	100	110	82	75	109
70% soil saturation	—	—	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

[a] Turkey winter wheat. [b] Java spring wheat.

with 27.0 bushels for the latter. The corresponding number of spikes per plant were 2.2 and 2.7; the spike lengths were 2.4 and 2.4; the total number of spikelets per spike was 14.5 and 14.6; the number of fertile spikelets per spike was 9.6 and 10.4; the number of sterile spikelets at the spike tip was 0.49 and 0.34; the number of sterile spikelets at the spike base was 3.9 and 3.9; the number of grains per spike was 16.0 and 18.4; and the average kernel weights were 0.019 and 0.024 grams.

The reduction in yield by this severe pasturing was brought about by a reduction of 19% in the number of spikes per plant, 13% reduction in number of grains per spike, and 21% decrease in average kernel weight. While the spike length and number of spikelets per spike remained practically the same, the number of fertile spikelets per spike reduced 7%.

RELATION OF GOOD AND POOR LOCATIONS IN THE SAME FIELDS TO SPIKE DEVELOPMENT

In order to study the effect of variation in soil productivity, samples of wheat were obtained from various farms within a radius of 10 miles north and east of Lincoln. Fields were selected that contained level fertile areas, and also hillsides which had been considerably eroded and were relatively infertile. Besides being more fertile, the soil on the level areas was physically much different from that of the slopes, and because of gradient, lost somewhat less rainfall by runoff. Random samples were taken from both good and poor locations in seven different fields in 1921 and six in 1922. The number of plants per unit area averaged 92% as great on poor locations as on good ones, and since the difference favored the individual plant development on the poor locations, it would tend to make them more nearly alike rather than to accentuate the plant differences. Tillering was reduced from 3.3 to 2.0 spikes per plant by poor locations and the total number of spikes per unit area was reduced 45%. The number of grains per spike was 24% less on the poor locations and since average kernel weight was practically the same (4% higher on the poor soil), the reduction in yield from 32.2 bushels to 14.4 bushels was due primarily to fewer spikes with fewer grains. The loss in number of grains per spike is due to the 12% reduction in number of fertile spikelets and the 14% decrease in grains per fertile spikelet. Spike length reduced from 2.4 inches on good locations to 2.1 inches on poor locations. With reduced spike length there was a corresponding reduction of 12% in number of spikelets per spike.

RELATION OF SOIL MOISTURE CONTENT TO SPIKE DEVELOPMENT

In order to study the effect of soil moisture limitation as a single factor, a series of 12 galvanized iron pots, 12 inches in diameter and 24 inches high, were filled with fertile Marshall silt loam soil and placed in the greenhouse in January, 1922. The pots were so filled that the soil occupied practically the same relative position as in the field. An inverted flower pot placed in the center of the soil and connected with the surface by means of a copper tube aided in supplying water rapidly. Three degrees of soil saturation were used, *viz.*, 35%, 45%, and 70% of the total water-holding capacity. The second degree, 45%, was included for use in case the 35% saturation point was too low for successful growth. Seventy per cent saturation was thought to be nearly the optimum for wheat growth in this soil. Two extra pots filled with soil were used in determining the saturation point of the soil. In this determination, water was added to the top of each pot and gravitational water was allowed to drain off through an opening at the bottom. When drainage ceased the soil was considered saturated. Knowing in advance the weight of the moisture-free soil in each pot, it was found to take 32.3 pounds of water for complete saturation. Four pots were then brought up by weight to each of the three saturation points desired and Java spring wheat, a relatively well-adapted spring variety, was planted. A 1-inch layer of fine quartz sand was added to the top of each pot to prevent excessive evaporation. Twenty well-spaced plants were allowed to grow in each pot. During the entire period of growth the pots were kept approximately at the desired degrees of saturation by weighing every one or two days, depending on conditions, and adding enough water, both at the surface and through the tube mentioned above, to make the desired weight. Growing conditions were generally favorable for the crop in the greenhouse and the plants made a better growth than spring wheat planted in the field the same year. One hundred and thirty-two days were required from date of planting to harvest.

Measurements and counts were made in the same manner used in the field studies. Grain yields were calculated on an area basis in bushels per acre. The yield was at the rate of 26.6 bushels on soil 35% saturated, 33.9 bushels on soil 45% saturated, and 41.1 bushels on soil 70% saturated. Wheat from soil 45% saturated showed characters intermediate between those of wheat on the higher and lower soil moistures in practically every regard. The 35% difference in yield between the highest and lowest soil moistures is accounted for by the reduction of 36% in tillering and 4% in number of grains per

TABLE 4.—*Comparison of the spike development on culms of different lengths from wheat planted at different dates, 1921.*

Culms arranged according to length (1)	Culm length, inches (2)	Spike length, inches (3)	Grains per spike (4)	Spikelets per spike					Spikelets per inch of spike (10)
				Number			Percentage		
				Fertile (5)	Sterile (6)	Total (7)	Fertile (8)	Sterile (9)	
Actual Values									
Turkey winter wheat planted Sept. 16[a]									
Longest 1/10	29.9	2.7	23.75	12.17	2.32	14.49	84.0	16.0	5.37
Shortest 1/10	15.2	1.8	8.37	6.03	6.26	12.29	49.1	50.9	6.83
Longest 1/3	28.2	2.6	21.98	11.65	2.68	14.33	81.3	18.7	5.51
Middle 1/3	24.9	2.4	18.61	10.22	3.33	13.55	76.6	23.4	5.65
Shortest 1/3	19.6	2.1	13.38	8.23	4.83	13.06	63.0	37.0	6.22
All culms	24.2	2.4	17.96	10.09	3.63	13.72	73.5	26.5	5.72
Turkey winter wheat planted Sept. 22[a]									
Longest 1/10	29.2	2.7	23.84	12.16	2.18	14.34	84.8	15.2	5.31
Shortest 1/10	18.1	2.0	10.76	7.24	5.05	12.29	58.9	41.1	6.14
Longest 1/3	27.9	2.6	22.44	11.73	2.34	14.07	83.4	16.6	5.41
Middle 1/3	25.4	2.5	19.34	10.63	3.10	13.73	77.4	22.6	5.49
Shortest 1/3	21.3	2.2	14.78	8.91	4.28	13.19	67.6	32.4	6.00
All culms	24.9	2.5	18.86	10.43	3.24	13.67	76.3	23.7	5.47
Turkey winter wheat planted Oct. 1[a]									
Longest 1/10	29.3	2.9	24.70	12.94	2.20	15.14	85.5	14.5	5.22
Shortest 1/10	18.4	2.1	12.59	7.94	5.34	13.28	59.8	40.2	6.32
Longest 1/3	27.9	2.8	22.75	12.24	2.51	14.75	83.0	17.0	5.27
Middle 1/3	25.4	2.6	20.60	11.52	3.06	14.58	79.0	21.0	5.61
Shortest 1/3	21.1	2.3	15.52	9.33	4.54	13.87	67.3	32.7	6.03
All culms	24.7	2.6	19.60	11.03	3.37	14.40	76.6	23.4	5.54
Turkey winter wheat planted Feb. 15[a]									
Longest 1/10	32.1	3.4	27.57	15.31	2.11	17.42	87.9	12.1	5.12
Shortest 1/10	15.1	2.4	10.33	7.94	7.11	15.05	52.8	47.2	6.27
Longest 1/3	29.9	3.3	24.83	13.98	2.39	16.37	85.4	14.6	4.96
Middle 1/3	26.5	3.1	21.60	12.92	3.30	16.22	79.7	20.3	5.23
Shortest 1/3	19.2	2.6	14.22	9.73	4.91	14.64	66.5	33.5	5.63
All culms	25.0	3.0	20.17	12.10	3.50	15.60	77.6	22.4	5.20

Percentage Relative Values

Turkey winter wheat planted Sept. 16[a]									
Longest 1/10	123.6	112.5	132.2	120.6	63.9	105.6	114.3	60.4	93.9
Shortest 1/10	62.8	75.0	46.6	59.8	172.5	89.6	66.8	192.0	119.4
Longest 1/3	116.5	108.3	122.4	115.5	73.8	104.4	110.6	70.6	96.3
Middle 1/3	102.9	100.0	103.6	101.3	91.7	98.8	104.2	88.3	98.8
Shortest 1/3	81.0	87.5	74.5	81.6	133.0	95.2	85.7	139.6	108.7
All culms	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Turkey winter wheat planted Sept. 22[a]									
Longest 1/10	117.3	108.0	126.4	116.6	67.3	104.9	111.1	64.1	97.1
Shortest 1/10	72.7	80.0	57.0	69.4	155.9	89.9	77.2	173.4	112.3
Longest 1/3	112.0	104.0	119.0	112.5	72.2	102.9	109.3	70.0	98.9
Middle 1/3	102.0	100.0	102.5	101.9	95.7	100.4	101.4	95.4	100.4
Shortest 1/3	85.5	88.0	78.4	85.4	132.1	96.5	88.6	136.8	109.7
All culms	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Turkey winter wheat planted Oct. 1[a]									
Longest 1/10	118.6	111.5	126.0	117.4	65.3	105.1	111.6	62.0	94.2
Shortest 1/10	74.5	80.8	64.2	72.0	158.5	92.2	78.1	171.8	114.1
Longest 1/3	113.0	107.7	116.1	111.0	74.5	102.4	108.4	72.6	95.1
Middle 1/3	102.8	100.0	105.1	104.4	90.8	101.3	103.1	89.7	101.3
Shortest 1/3	85.4	88.5	79.2	84.6	134.7	96.3	97.9	139.7	108.8
All culms	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Turkey winter wheat planted Feb. 15[a]									
Longest 1/10	128.4	113.3	136.7	126.5	60.3	111.7	113.3	54.0	98.5
Shortest 1/10	60.4	80.0	51.2	65.6	203.1	96.5	68.0	210.7	120.6
Longest 1/3	119.6	110.0	123.1	115.5	68.3	104.9	110.0	65.2	95.4
Middle 1/3	106.0	103.3	107.1	106.8	94.3	104.0	102.7	90.6	100.6
Shortest 1/3	76.8	86.7	70.5	80.4	140.3	93.8	85.7	149.5	108.3
All culms	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a] The Turkey wheat grown in this test was a pure strain known as Nebraska No. 60.

TABLE 5.—*Comparison of the spike development on culms of different lengths from wheat from good and poor locations in the same fields, 1921.*[a]

Culms arranged according to length (1)	Culm length, inches (2)	Spike length, inches (3)	Grains per spike (4)	Spikelets per spike Fertile (5)	Spikelets per spike Number Sterile (6)	Spikelets per spike Total (7)	Spikelets per spike Percentage Fertile (8)	Spikelets per spike Percentage Sterile (9)	Spikelets per inch of spike (10)
Actual Values									
Wheat from poor locations									
Longest 1/10	25.1	2.3	20.9	10.70	3.24	13.94	23.2	76.8	6.06
Shortest 1/10	16.0	1.6	9.69	5.28	4.83	10.11	48.8	51.2	6.32
Longest 1/3	24.0	2.1	19.00	10.33	3.44	13.77	25.0	75.0	6.56
Middle 1/3	21.9	2.0	16.36	9.17	3.80	12.97	29.3	70.7	6.48
Shortest 1/3	18.6	1.7	12.63	7.57	4.32	11.89	36.3	63.7	6.99
All culms	21.5	2.0	16.00	9.03	3.96	12.99	30.5	69.5	6.49
Wheat from good locations									
Longest 1/10	34.9	2.7	23.85	12.80	3.32	16.12	20.6	79.4	5.97
Shortest 1/10	22.8	2.0	13.34	8.48	5.28	13.76	38.4	61.6	6.88
Longest 1/3	33.2	2.6	22.50	12.28	3.73	16.01	23.3	76.7	6.16
Middle 1/3	29.9	2.4	19.74	11.01	4.12	15.13	27.2	72.8	6.30
Shortest 1/3	25.6	2.1	15.93	9.50	4.73	14.23	33.2	66.8	6.78
All culms	29.2	2.4	19.30	10.92	4.26	15.28	25.7	74.3	6.37
Percentage Relative Values									
Wheat from poor locations									
Longest 1/10	116.7	115.0	125.6	118.5	81.8	107.3	76.1	110.5	93.4
Shortest 1/10	74.4	80.0	60.6	58.5	122.0	77.8	160.0	73.7	97.4
Longest 1/3	111.6	105.0	118.7	114.4	86.9	106.0	82.0	107.9	101.1
Middle 1/3	101.9	100.0	102.2	101.6	96.0	99.8	96.1	101.7	99.8
Shortest 1/3	86.5	85.0	78.9	83.8	109.1	91.5	119.0	91.7	107.7
All culms	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Wheat from good locations									
Longest 1/10	119.5	112.5	123.6	117.2	77.9	105.5	80.2	106.9	93.7
Shortest 1/10	78.1	83.3	69.1	77.7	124.0	90.1	149.4	82.9	108.0
Longest 1/3	113.7	108.3	116.6	112.5	87.6	104.8	90.7	103.2	96.7
Middle 1/3	102.4	100.0	102.3	100.8	96.7	99.0	105.8	98.0	98.9
Shortest 1/3	87.7	87.5	82.5	87.0	111.0	93.1	129.2	89.9	106.4
All culms	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a] The data are the average of seven different fields, representative samples being taken from eroded slopes and fertile level areas in each field. Turkey winter wheat used in each case.

spike. Average kernel weight was actually 10% greater on wheat from the drier soil, but this only in part offset the disadvantage of lessened tillering and number of grains per spike. There was no difference in spike length on the two soils, but wheat from the dry soil had an average of 15% fewer spikelets per spike. There was a difference of only 6% in the number of fertile spikelets per spike, however. Wheat in the dry soil had 2% more grains per fertile spikelet.

METHOD OF STUDY

In any experiment where the relative spike development is an important issue it becomes a serious problem to determine what constitutes a typical spike or representative group of spikes for the condition under consideration.

May reliable comparative results be obtained by selecting only the outstanding main spikes which are commonly borne on the tallest culms, or should all spikes of the plants including those borne on tillers be taken into consideration? The data in Tables 4 and 5 indicate the variability of spike development in relation to culm height. The data have been grouped for any one condition according to culm height into the tallest 1/10, shortest 1/10, tallest 1/3, intermediate 1/3, shortest 1/3, and the mean of all culms.

TABLE 6.—*Relative spike development of the main culms and tillers of Turkey winter wheat grown under field conditions. 1923.*

Plant characters	Main culms	Tillers bearing spikes	Ratio
Number of main culms and stools	84.0	288.0	3.43
Culm length (inches)	39.5	36.6	0.93
Spike length (inches)	3.10	2.63	0.85
Total number spikelets per spike	16.94	15.59	0.92
Fertile spikelets per spike	13.97	11.56	0.83
Sterile spikelets at spike tip	0.24	0.28	1.17
Sterile spikelets at spike base	2.97	4.00	1.35
Spikelets per inch of spike	5.46	5.93	1.09
Per cent fertile spikelets (per cent)	82.3	74.2	0.90
Per cent sterile spikelets	17.7	25.8	1.46
Grains per spike	27.0	20.8	0.77
Grains per fertile spikelet	1.95	1.8	0.92
Average kernel weight (grams)	0.024	0.022	0.92
Ratio spike length to culm length (per cent)	7.85	7.18	0.91
Fertile spikelets per inch culm	3.54	3.16	0.89
Sterile spikelets per inch culm	0.076	0.110	1.45
Total spikelets per inch culm	0.430	0.425	0.99

It is apparent that discriminate selection of the main spikes as represented largely by the tallest culms would not provide representative material. Neither would choice of any of the other subclasses furnish typical results. The main culms of 100 Turkey wheat plants were tagged when their heads first emerged from the leaf boots. When mature the plants were carefully pulled by the roots for laboratory comparison of the respective spike development of the main culms and stools of the same plant. The inferior development of the tillers compared with the main culm is seen throughout in Table 6. For this type of study at least it would seem desirable to utilize all spikes produced by plants selected at random.

SUMMARY

1. Under Nebraska conditions the fall growth of winter wheat is commonly restricted to crown, basal leaves, and roots. Except in the case of far earlier seeding than is ever practiced under farm conditions, wheat does not joint in the fall. Normally, there is no elongation of culm internodes in the fall, except the lower one which serves to raise the crown when the seed is deeply planted, and there is no spike development. At the crown each stem has several very short internodes, above these is the smooth conical growing point still giving rise to leaves and new internodes of the stem when winter dormancy sets in.

2. Almost immediately upon the resumption of spring growth in March the culms commence elongation and the growing tips become more prominent. Coincident with the continued culm growth, the growing tips enlarge and begin differentiation into spikes about April 1. In the case of normal growth, the total number of spikelets which obtain at maturity may be readily ascertained by May 1 which is one month before the full heading stage and two months before ripening. At this time the spike does not exceed one-tenth inch in length.

Spikelets are formed at the base of the spike first and at the tip last, but the median spikelets soon become the largest and retain this advantage to maturity. Early in May flowers may be observed within the spikelets. Of the eight or nine flowers per spikelet apparent at this stage, only the lower one to three develop to maturity, while the others remain rudimentary, dry up, and disappear. Several of the basal spikelets and occasionally one or two of the tip spikelets remain sterile.

3. The time of spike differentiation varies with cultural practices and environmental conditions.

4. The tiller culms of wheat plants are shorter and produce shorter spikes than the main culms. They also produce fewer fertile spikelets, total spikelets, grains per spike, and grains per fertile spikelet, and lighter kernels. There are more sterile spikelets on these lesser spikes.

5. Selecting spikes discriminately in a field for a study of this kind will likely result in high experimental error, due to unequal variations in plant characters under different environmental conditions. It appears that all the spikes borne on plants obtained by random selection should be considered.

6. Adverse environmental and cultural conditions, such as severe pasturing, thick rates of seeding, late dates of seeding, low soil fertility, and low soil moisture, cause reduced vegetative growth and lower yields of grain.

7. Yield of grain per acre is an expression of three combined factors (a) The number of spikes per unit of area, (b) the number of grains per spike, and (c) the average weight of the kernels.

8. The number of spikes per unit of area is affected by the number of plants and the rate of tillering. The number of plants normally depends on the rate of planting Tillering decreases under the conditions named in 6.

9 The number of grains per spike depends upon the number of its fertile spikelets and the number of grains per fertile spikelet. In these tests the number of grains per spike was increased with delayed seeding, doubtless due to thinner stands resulting from reduced stooling, but decreased with thick seeding, severe pasturing, low fertility of the soil, and low soil moisture.

10. The average kernel weight decreased with late dates of seeding, thick rates of seeding, pasturing, and abundance of soil moisture, but was little affected by the wide range of soil fertility of these experiments.

11. Adverse soil conditions which tend to stunt growth, reduce the straw yields more than the grain yields. Straw yields were reduced by late seeding, thick or thin seeding, pasturing, infertile soil, and low soil moisture. The ratio of grain to straw was reduced by late planting and by thick planting, and increased by infertile soil and low soil moisture.

12. Environmental conditions which reduce vegetative growth generally cause a reduction in tillering, culm length, spike length, number of fertile and total spikelets per spike, grains per spike, grain and straw yields, average kernel and culm weights, grains per fertile spikelet, and percentage of fertile spikelets.

13. These same conditions generally cause an increase in number of sterile spikelets, in ratio of spike length to culm length, in number of fertile, sterile, and total spikelets per inch of culm, and in percentage of sterile spikelets.

14. Although it is possible to determine the approximate number of spikelets per spike long before emergence of the head, such a count cannot be reliably used for an early prediction of relative grain yields. The percentage of sterile spikelets and the average kernel weight of the prospective crop are still dependent upon the nature of the ensuing growth conditions.

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COOPERATIVE RESEARCH IN PLANT PHYSIOLOGY AND AGRONOMY[1]

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A meeting such as this augurs well. It establishes, beyond question of doubt, the recognition of the mutual interrelation and interdependence of agronomy and plant physiology. It offers an opportunity for the discussion of principles and for an exchange of views so vital for the proper and permanent association of the two fields. Plant physiology, started in an agricultural academy by Julius von Sachs more than sixty years ago, now offers the accumulated results of its researches to scientifically trained agronomists fully capable of appreciating their value and of applying them in their chosen field. Yet agronomists complain that although they eagerly scan the researches of plant physiology, too often, they find them wanting in the specific materials they most need in agronomy. Physiologists must frankly admit this to be true. This science was born and nursed in an agricultural academy, continued to prosper when divorced from its early associations, but soon drifted into fields more remote from and less intimate with the practice of agriculture. In place of studying the functional phases of the plant as affected by external conditions, physiologists gradually drifted into intensive studies of specific functions, without attempt or thought of connection with some important practice. Undue dominance has been given to the "pure" and theoretical, and the very phase of the science from which the greatest and most lasting returns may be expected has been neglected. Agronomists recognize that the real progress of their science will have to depend chiefly upon a foundation furnished by plant physiology; and plant physiologists find that their greatest opportunity to extend the boundaries of knowledge in their field lies in the practical problems which the experience of the agronomist suggests. It is perfectly clear, then, that the contributions of plant physiology must be scientific and practical, and that the physiologist must necessarily study the problems that perplex the agronomist. The keynote to success, here as elsewhere, lies in intimate and mutual cooperation.

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This mutual task is a large and difficult one. The plant, upon which the success of the agronomist depends, is an intricate mechanism with many and diverse functions, accelerated, inhibited, and modified by soil heterogeneity, water and temperature variations and extremes, gases, light, etc. To cope successfully with problems of such fundamental importance, the plant as a responsive organism must be given chief attention; and agronomists, plant physiologists, and soil physicists must bury their petty jealousies and break down the sharp lines of divisional authority, and resolutely strive, each in his own field, to solve the intricate interrelations between the plant and its environment.

For a successful and rapid elucidation of a problem of this nature, it seems that several institutions might well enter into a cooperative agreement. In such a plan the distribution of the several phases of the problem would be determined by the laboratory and field equipment of the institution, and the interest and training of its personnel. A relation of this nature once established, with the objective always clearly in mind, and the method and training of the agronomist, of the soil physicist, and of the plant physiologist kept distinct and individual, but coordinated, the successful solution of the most refractory problems can be achieved. It is the solution of large and fundamental problems and not the accumulation of isolated facts that will hold interest and determine rates of progress. It is the united action of men of diverse training and interest, centered on a common experimental project, that will lead to success. But the individual worker must not be deprived of a full and perfect freedom in technic and action. His field, defined in a project by a committee of which he is an active member, is to be developed by his own initiative. It must remain individual research properly coordinated through a well defined project.

The several divisions of the department of agronomy and plant physiology of the University of Illinois have for the past two years been working under such a cooperative plan. It is not perfected, but the results already achieved justify its continuance. The committee on projects has had a number of meetings and has outlined a number of major and minor projects. In these the plant occupies the position of importance which justly belongs to it. Experimental work thus far planned and under way pertains to the germinative and early seedling phases. These studies offer, first, a logical beginning for a complete understanding of the physiology of the plant in its successive developmental stages and physiologic phases; second, a prospect for understanding the causes that lie at the base of the high "infant mortality," and for discovering ways and means of preventing it; and, third, an opportunity for learning the effect that soil and climatic variations may have in predetermining the yield.

The most important feature in the prosecution of work of this nature is experimental control. This was provided in special plant houses, shown in Fig. 1. These houses are provided with equipment for the control of soil and air temperature, humidity, light, etc., shown in Fig. 2. Equipment of this nature is expensive in installation and maintenance, and the more intricate phases of some of the investigations must be left for specially equipped institutions, such as the Boyce Thompson Institute for Plant Research. This is the chief reason for cooperation; and for the larger problems, this will of necessity be not only intra-departmental but inter-institutional. Each institution can arrange to equip and maintain one or several of the more expensive control devices. Through mutual agreement, problems requiring control apparatus of special kind should be referred to the institution best equipped for that specific investigation. On several occasions, the University of Illinois has given visiting investi-

FIG 1 — General view of the experimental laboratories in plant physiology, at the University of Illinois

A small part only of the glass structure is devoted to the growing of plants. It is equipped with special control apparatus for light, temperature, humidity, etc The building in the background is devoted largely to the chemical phases of physiology

FIG. 2.—One of a series of six cases maintaining constant temperatures of 5°, 10°, 15°, 20°, 25°, and 30°C., respectively. Accessory control apparatus make possible the control of humidity, etc.

gators the free use of its laboratories and apparatus for researches which could not be successfully completed with the facilities at their disposal elsewhere.

Much of the control apparatus serves most adequately the purpose for which it was devised. But for some of the newer problems its use is not altogether apt. The plant, in the light of its morphological differentiation and its concomitant physiologic behavior, must be considered a dynamic organism. Too generally it has been considered as a static organism, and consequently methods of experimentation have been too largely those of physics and of chemistry rather than of biology. No one would advocate the disuse of the equipment or the abandoning of methods that in the past have served well. On the contrary, these will always be needed for the study of specific functions as affected directly by chemical and physical agents. However, there is needed for the study of newer and larger problems, apparatus that will make it possible to subject the plant under experimentation more nearly to the constantly varying conditions to which in nature it is exposed, that is, will simulate its natural environment. To have their highest practical and scientific significance, the series of studies on the germinative and early developmental phases of the seedling above mentioned must be carried on under conditions that, as nearly as possible, approach the natural In the corn belt the climatic conditions during seeding and planting time are very variable from season to season and are, in large measure, responsible for the variation in yield.

In studies of this nature the apparatus that maintains the several factors of temperature, humidity, soil moisture, light, etc., at uniform and constant levels is distinctly less advantageous than that which, at the will of the experimenter, automatically varies these factors according to the natural diurnal variations. By the use of especially constructed thermostats, humidostats, resistances, etc., it should be possible to secure an almost endless combination of conditions. The temperature, moisture, etc., rise and sink, with an occasional very low morning temperature such as is likely to occur in the corn belt. It is further to be mentioned that the several factors can be independently adjusted and maintained so that there may be maintained high temperature and low humidity, or the reverse.

The occasional very low or very high temperatures, together with low or high moisture content of the soil and air humidity, are receiving special attention. Somewhere in the range of variation in these factors the delicately adjusted mechanism of the plant becomes deranged—the critical point—and a series of ills follow. Naturally, each crop shows its distinctive reaction to these environmental factors and hence requires a different adjustment in the range of variation. This applies also to fungus and host. The relation of temperature, etc., to fungous injury has been extensively investigated at Wisconsin. The results of these investigations have been discussed as a part of this symposium by Dr. Dickson. In these temperature relations, our own experiments show that at the critical point the chemical processes in the cell apparently undergo marked changes and the cell membranes lose in some measure their semi-permeable nature and allow an undue diffusion of organic materials to take place.

Each phase in the structural differentiation of the plant determines a new environmental and functional relation. This was recognized by Sachs when he said, "Das Organ ist Heute nicht mehr dasselbe Ding wie Gestern und wird Morgen wieder ein Ding mit anderen Eigenschaften sein, selbst wenn man das an der aussern Form und der mikroskopischen Struktur nicht wahrnimmt" The developmental stages and physiological phases of the plant need constatn consideration. Similarly, graded environmental factors playing up on seedlings of only slightly different developmental, and hence physiologic phases, often give very different reactions. These reactions may manifest themselves very early or they may not become apparent until late in the growth or reproductive phases. In the latter case, the effect of the early environmental factors are not temporarily lost as might be supposed, but the transitional phases are not recognized owing to insufficient experience. The end phases are the natural sequence of a chain of changes induced by a change in the environment. This is called, by Kidd and West, "physiological predetermination" Much work must be done along this line and efforts are being made to find in some of the common vegetable and grain crops the physiological phases or critical periods in the life of the young plant, when an unfavorable environment affects most significantly the minus of plant production. Naturally, this is paralleled by a study of the nature of the factors, etc , that affect a plus in plant production.

Soil and climatic conditions have long been considered operative agents in modifying the nature and character of plant growth. The importance of the climatic factors were recognized on a large scale by the forestry service of the German Empire. It is said that the collectors for the forestry service who are collecting seeds in foreign countries for planting in Germany are instructed to select only from such sources of supply as are most nearly identical in soil and climate to the locality in which the forest is to be planted. Many agronomists

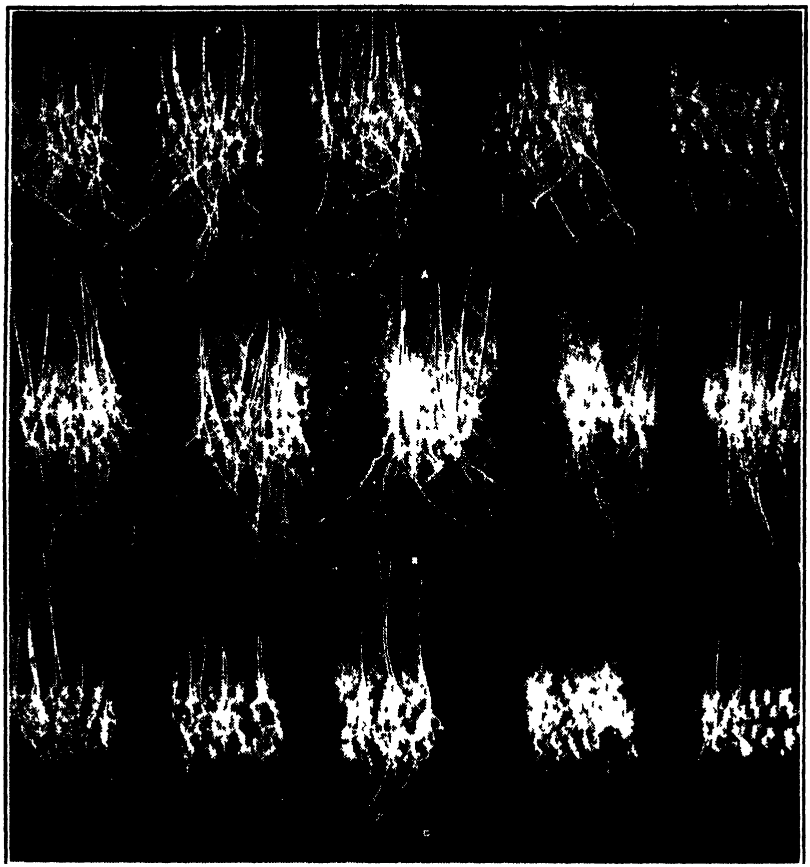

FIG. 3.—Wheats: 1, Marquis, 2, Red Cross, 3, Illinois No. 1; 4, Turkey Red; and 5, Golden Chaff, subjected to dry heat at 112°C. for 15 minutes. A, uninjured seed coats B, random sample. C, seed coats injured over embryo.

have learned the difference in results obtained by the planting of seed corn obtained north or south of their own locality

Another project under investigation is a comparative field and laboratory study of varieties of wheat, corn, and soybeans Time will permit me to refer only to some of the more interesting results, and to discuss them very briefly Among the more significant results obtained with wheat is the wide difference in behavior of different varieties to sub- and supra-normal temperatures and soil moistures, and the relation of these effects to the nature of the seed coat. Of still greater interest is the variation in behavior of the individual

FIG. 4—Wheats 1, Marquis; 2, Red Corn, 3, Illinois No. 1; 4, Turkey Red; and 5, Golden Chaff, treated for three hours in water at 50°C.
A, uninjured coats B, injured coats.

kernels of a tested and supposedly pure variety to these temperature conditions From the results obtained in some varieties it seems perfectly apparent that there are physiologic strains within the variety By subjecting the different varieties to a progressively severer treatment, it has been found that some varieties, as would be expected, show an increasingly harmful effect and that at the critical stage death occurs. In other varieties, as the severity of the treatment increases, the death of numbers of kernels at several stages occurs, thus indicating the inability of the different physiologic strains to withstand the rising or sinking temperature. This in all probability is the reason why a given variety gives uniformly good stand and yield for several years in succession, and then, under slightly different (lower) temperature conditions, a partial or complete failure.

Studies of the relation between broken seed coats and fungous infection are interesting and important. In work on wheat it has been found that broken seed coats likewise increase the harmful, and in many cases, destructive effects of sub- and supra-normal temperatures. In earlier experiments random samples of threshed wheat were used. It became necessary to abandon this practice because of the varying injury to the coats of different varieties in the threshing process. Random samples of the varieties listed below give the injuries as indicated.

Variety	Unbroken coat %	Broken coat %	Broken kernels %
Marquis	47	32	21
Red Cross	48	44	8
Illinois No. 1	49	47	4
Turkey Red	66	30	4
Golden Chaff	55	31	14

When kernels of the above varieties with unbroken coats, with broken coats, and random samples are subjected for 15 minutes to dry heat at 112°C., and then placed under similar conditions for germination, the effects shown in Fig. 3 are clearly defined. Even in the unbroken coats, as shown in Fig. 3, A, injury is apparent both in the number of grains germinating and the prevalence of *Rhizopus*. The difference in the ability to withstand this condition in the respective varieties, Marquis, Red Cross, Illinois No. 1, Turkey Red, Golden Chaff, also is clearly shown, Turkey Red and Golden Chaff (4 and 5) being most injured. The result of a similar experiment bringing out even more markedly the protection of an uninjured seed coat is shown in Fig. 4. Here the several varieties were immersed in water at 50°C. for three hours, Series A with injured seed coat, Series B injured over embryo.

Time will not permit further discussion of experiments in progress. Enough has been presented to make clear the type of organization and aims, and to indicate the application in practice of the departmental cooperation which shall ensure successful research.

BOOK REVIEW

CROP PRODUCTION IN INDIA: A CRITICAL STUDY OF ITS PROBLEMS

By Albert Howard, Director, Institute of Plant Industry, Indore, India. Oxford University Press, Cambridge, England. 200 pp. 1924.

The author of this little volume is a man with a wide agricultural and scientific experience in India, formerly as Imperial Economic Botanist, Pusa, now Director of the Institute of Plant Industry at Indore. The book is divided into three parts which deal with the soil, the crop, and the organization of research.

Chapter headings are as follows: Part I: Surface Drainage and Erosion; Soil-aeration; Irrigation and Water Saving; The Nitrogen Problem; The Alkali Problem. Part II; The Economic Significance of Root Development; The Improvement of Varieties; The Distribution of Seed; Some Aspects of the Fodder Problem; Cotton; Wheat; Rice; Sugar Cane; Fibres; Oil Seeds; Tobacco; Pulses; Fruit Growing;

Disease in Plants Part III: The Ideal Investigator; The Organization of Research. A short bibliography is appended to each chapter.

In the preface, the author draws attention to the fact that agriculture is, and for many years to come must remain, India's greatest industry and the foundation of the state. The chief aim of the book is to set out some of the problems of crop production in simple language, so as to secure the active cooperation and interest of the public. Another aim is to stimulate further work and to attract a number of active and enthusiastic investigators to the field of agricultural research.

The author has placed emphasis on the importance of increasing knowledge and understanding of the root systems of crop plants. This is the subject of the first chapter in Part II and is referred to many times in the later chapters of the book

In his chapter on Disease in Plants, it is pointed out that the study of the diseases of crops is entering on a new phase. In the future, the studies of plant pathologists must include not only the parasites involved, but the general physiology of the plant, the life history of the root system, the relation of soil factors, and of temperature and humidity to the life of the plant. Part III will interest not only those actively engaged in research or teaching in soils and crops, but also those charged with the administration of these and related lines of work. According to the author, the form of organization to be adopted must simultaneously fulfill two conditions; (1) freedom for the investigator, (2) proper control of the money provided for the work. Some compromise—in which the reasonable requirements of the men who do the work and the interests of the public who provide the money are reconciled—is needed, if science is to take its proper place in the nation building of the future. The difficulty, according to the author, is not so much the provision of funds as the happy union of ability and opportunity with the means required

According to the author, the ideal investigator must be well trained in all branches of botanical science, including morphology, anatomy, physiology, pathology, systematic botany, ecology and genetics. In addition he must have a sound knowledge of general science, in which chemistry and physics should be included. To the reviewer this seems a "large order," though the value of such training cannot be denied.

Certainly no American agricultural college or experiment station library will want to be without a copy of "Crop Production in India." It is likely that many teachers and investigators, not only in agronomy, but also in botany, plant pathology, plant breeding and related subjects will find this book worth adding to their own working libraries. The reviewer heartily recommends the book to this group of workers, and to graduate students, who will certainly be interested in the author's statement that there is at present a shortage of workers capable of dealing with crop questions (JOHN H. PARKER)

AGRONOMIC AFFAIRS

INTERNATIONAL CONGRESS OF PLANT SCIENCES

(Fourth International Botanical Congress)

Investigators and teachers in the plant sciences, representing all aspects of botany, plant chemistry, plant pathology, and bacteriology, agronomy, horticulture, and forestry are invited to attend the International Congress of Plant Sciences to be held at Ithaca, N. Y., August 16–23, 1926. This invitation is extended to all countries of the world.

This Congress is scheduled to follow the usual academic sessions abroad, also the short summer sessions of the various universities and colleges in the United States. It is believed to offer the first opportunity ever arranged in the United States for a general conference of all those professionally engaged in plant work. It possesses the additional compelling interest accruing from unrestricted international representation.

In order that a part of the program may be representative of outstanding leadership, the Congress will be divided into about one dozen sections, each section with an invitation program occupying about four morning sessions or a little more than one-fourth of the available time. These formal programs will be supplemented by another feature that promises also to be of exceptional interest. Ample time will be set apart for round table or informal discussions, which in some cases may be scheduled in advance, and in others may be arranged both as to topics and participation after the Congress actually convenes. This is intended to provide for the widest participation in sectional activities. Supplementary opportunities for individual contact and participation are made possible through the non-commercial exhibits and through the provision for excursions and inspection tours of various types suited to the diverse needs of the different sections.

Although the Congress is not to provide an occasion for *legislation* on regulatory matters of international significance (such as nomenclatorial rules) the organizing committee has expressly provided that "adequate opportunity shall be accorded all sections for the *discussion* of regulatory recommendations of international significance," in order that a better understanding may be reached for definite action at a subsequent international congress.

The sections thus far authorized and the secretaries representing these groups are as follows:

Agronomy—C. H. Myers, Cornell University, Ithaca, New York.
Bacteriology—J. M. Sherman, Cornell University, Ithaca, N. Y.

Cytology—L. W. SHARP, Cornell University, Ithaca, N. Y.

Morphology, Histology and Palso-botany—D. S. JOHNSON, Johns Hopkins University, Baltimore, Md.

Ecology—H. L. SHANTZ, Bureau of Plant Industry, Washington, D. C.

Horticulture—A. J. HEINICKE, Cornell University, Ithaca, N. Y.

Physiology—O. F. CURTIS, Cornell University, Ithaca, N. Y.

Pathology—DONALD REDDICK, Cornell University, Ithaca, N. Y.

Pharmacognosy and Pharmaceutical Botany—H. W. YOUNGKEN, Massachusetts College of Pharmacy, Boston.

Taxonomy—K. M. WIEGAND, Cornell University, Ithaca, N. Y.

Forestry—R. S. HOSMER, Cornell University, Ithaca, N. Y.

Genetics—C. E. ALLEN, University of Wisconsin, Madison, Wisconsin.

Mycology—H. M. FITZPATRICK, Cornell University, Ithaca, New York.

Communications regarding the Congress should be addressed as indicated below:

(1) Concerning round tables and other strictly sectional matters—to the appropriate sectional secretary.

(2) Concerning exhibits and general program matters—L. W. Sharp, Cornell University, Ithaca, N. Y.

(3) Concerning excursions, collecting trips, inspection tours, local arrangements, transportation, etc.—H. H. Whetzel, Cornell University, Ithaca, N. Y.

(4) Concerning the Congress in general—B M. Duggar, Missouri Botanical Garden, St. Louis, Mo.

LIST OF MEMBERS OF THE SOCIETY

In response to numerous requests that a list of the members of the Society be published in the JOURNAL, the Secretary has prepared the following list as representing the membership on January 1, 1926.

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KASSABZADE, SHUKRI HUSSEIN, Dept. of Agr., Robert College, Constantinople, Turkey.

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President Williams has appointed the following members of the Society to constitute the several standing committees for 1926.

COMMITTEE ON AGRONOMIC TERMINOLOGY

C. V. Piper, *Chairman*, C. R. Ball, H. L. Shantz.

COMMITTEE ON STANDARDIZATION OF FIELD EXPERIMENTS

S. C. Salmon, *Chairman*, T. A. Kiesselbach, H. H. Love,
C. A. Mooers, L. J. Stadler.

COMMITTEE ON VARIETAL STANDARDIZATION

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J. H. Parker, T. R. Stanton, R. G. Wiggans.

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H. V. Harlan, *Chairman* (1926)	T. R. Stanton, *Chairman* (1926),
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A. G. McCall (1928) T. A. Kiesselbach (1930)

COMMITTEE ON COOPERATION WITH THE UNION OF BIOLOGICAL SOCIETIES

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The President has also appointed the following as members of the several special committees to serve during the year 1926:

COMMITTEE ON CORN PROJECTS UNDER THE PURNELL ACT

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SYMPOSIUM ON "SOIL DETERIORATION"

Leader: S. B. Haskell, Director, Massachusetts Agricultural Experiment Station

1. "The Allegation of Deterioration."
   - A. "Analysis of Crop Yield Statistics." B. O Weitz, Bureau of Economics, U. S. Department of Agriculture
   - B. "The Testimony of the Field Experiments of the Country." C. G. Williams, Ohio Agricultural Experiment Station
2. "The Causes of Soil Deterioration." Brief summations showing:
   - a. "Determined and Measured Fact and its Interpretation" and
   - b. "Unproved Theories and Hypotheses Representing the next Steps in Research"
   - A. "Changes in Character, Condition, and Amount of Organic Matter." Oswald Schreiner, Bureau of Plant Industry, U. S. Department of Agriculture
   - B. "The Development of Toxic Conditions." B. L. Hartwell, Rhode Island Agricultural Experiment Station
   - C. "The Removal of Plant Nutrients in Drainage Waters." J. A. Bizzell, Cornell University
   - D. "Changes in the Microbiological Complexes of the Soil." S. A. Waksman, New Jersey Agricultural Experiment Station
   - E. "Soil Harbored Insects and Fungi."
     - a. "The Rôle of Insects in the Soil." J. W. McColloch, Kansas Agricultural Experiment Station
     - b. "The Relation of Fungi to Soil Deterioration." L. R. Jones, University of Wisconsin
   - F. "Waste through Soil Erosion." M. F. Miller, University of Missouri
3. "Public Policy and Soil Deterioration."
   - A. "Public Land Policy." E. T. Ely, Northwestern University
   - B. "Crop Prices and Soil Deterioration." G. F. Warren, Cornell University (Read by title only)

1A. AN ANALYSIS OF CROP YIELD STATISTICS WITH REFERENCE TO SOIL DETERIORATION[1]

B. O. Weitz[2]

Once more warnings of overpopulation and impending food shortage are being sounded. With practically all of our good agricultural land available without reclamation already in use and the recognition that any further expansion of our crop area will be on lands poorer or more expensive to reclaim than those already in cultivation, speculation is rife as to the future trend of the volume of agricultural production. Students of the problem are taking stock of our land resources, and once more with a steadily growing population the name of Malthus is becoming familiar to many lips.

The threatened disappearance of our export surplus of bread grains as a result of the relatively short crop of wheat harvested this year has aroused considerable discussion not only in the United States but also in the densely populated countries of northwestern Europe. Both in Germany and England great emphasis is again being laid on the necessity of increasing agricultural production. In Germany especially the ultimate goal hoped for is absolute self-sufficiency from the standpoint of food production.

With the greater part of our available agricultural area already in use, the problem of productivity and soil fertility is now coming to the fore as one of the most important phases of the land utilization problem.

Ignoring the question concerning how long our export surplus of wheat and food products will continue, we are doubtless, sometime in the immediate future, going to face the problem that confronted northwestern Europe in the latter half of the nineteenth century, namely, that of bringing about an increase in agricultural production on the lands now under cultivation by the use of more intensive methods.

Within the short time allotted to me I do not wish to become involved in a discussion of the population and food production problem which was discussed so thoroughly in the recent session of the Institute of Politics, but the foregoing is the background of the renewed interest in the alleged deterioration of our soils. Since the word alleged is usually coupled with the word deterioration, it may be construed that our soils are still to be proved guilty of the charge of deterioration.

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[1] Paper read as a part of the symposium on "Soil Deterioration" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] Junior Agricultural Economist, Division of Land Economics and Land Utilization, Bureau of Agricultural Economics, U. S. Department of Agriculture, Washington, D. C.

PROBLEM OF SOIL DETERIORATION AND FERTILITY MAINTENANCE

Historically, the problem of soil deterioration and maintenance of soil fertility seems to be an age-old one. Migrations of peoples in early times are in many cases attributed to soil depletion. Frequent references are to be found in the writings of both Latin and Greek writers that indicate a recognition of the fact that soils when managed in certain ways do decline in productivity. However, it is only within a comparatively recent time that the importance of the problem achieved wide recognition.

The so-called agricultural revolution had its beginning 150 to 200 years ago, but comparatively little progress was made in bringing about a widespread use of improved methods of soil management until the latter half of the nineteenth century with the exception of that which occurred in England during the latter decades of the eighteenth century.

In Europe this was hastened by the pressure of the rapidly increasing population and the profound changes in the economic and social condition of the people caused by the industrial revolution. But it was not until the publication of the work of Liebig, whose contribution added much to our knowledge of the intimate relation existing between soil productivity and methods of soil management, that the great change in methods came

In the United States the problem of soil deterioration, although discussed considerably in the East during the early part of the nineteenth century, has only recently become national in its significance. Bishop Berkeley is credited with coining the epigram "Westward the course of empire takes its way," and some twenty years ago Dr. C. G. Hopkins added to this epigram the words, "leaving impoverished lands behind." As I shall attempt to show in the present paper, however, in the statistical history of crop yields one must seek in vain for proof of Dr. Hopkins' contention.

SOURCES AND NATURE OF CROP YIELD STATISTICS AVAILABLE

I have been asked to consider the alleged deterioration of our soils by an analysis of crop yield statistics.

The period for which annual crop yield statistics are available is relatively short not only in the United States but also in Europe. Crop reporting systems are largely a development of the second half of the past century. Previous to the past 50 or 60 years the literature of crop yields is scant and fragmentary. The small amount of material is based largely on the personal observation of certain men.

In the United States it was not until after the Civil War that the Department of Agriculture began the publication of annual estimates of crop yields. The questionnaire of the tenth census in 1880 included questions on both acreage and production of crops, making available for the first time crop yield data based on actual enumeration. Various states have also maintained statistical organizations that published annual estimates of crop yields within those states. It is worth noting that the Federal census of 1880 indicated that previous to that time the yield estimates published by the United States Department of Agriculture and also those published by some of the state authorities were higher than the real yields.

Publication of crop yield figures in the northwestern European countries began during the seventies and eighties of the past century with one exception, France, where yield estimates have been available since the end of the Napoleonic wars.

The materials cited above furnish practically the only authoritative data available on the history of crop yields for countries and minor civil divisions.

It is recognized that yield statistics for a large area such as a country or a state do not show the deterioration or improvement that is occurring on individual fields or farms. They do indicate, however, the trend in the average condition of the area.

The trend in yield per acre of a crop over a long period in a given area will be a reflection of two sets of forces working in opposite directions; one group of factors tending to raise yields, the other to depress them.

In the following discussion emphasis is laid primarily on changes that have occurred in what might be called the general level of yields at different times in the period covered by the data.

Have average crop yields been going up, down, or are they stationary? Is absolute soil depletion a fact borne out by historical evidence?

INDICATIONS OF CROP YIELDS PRIOR TO 1850

In discussing the nitrogen problem, Albert Howard in his book "Crop Production in India" states, "As far as combined nitrogen is concerned, a rough condition of equilibrium has been reached in Indian agriculture. The annual gains and losses are about equal. This is indicated by the records of crop production in the United Provinces from the time of Akbar down to the present day. For the last three hundred years the producing power of the soil has not appreciably changed."

From the rather scant data available for the period preceding the modern era in Europe, it is evident that crop yields were at a very low level. In England (1)[3] during the middle ages wheat yields ranged from 6 to 10 bushels per acre. On the continent yields were probably not any higher. Under the common field system the soils had long before the end of the medieval era lost their power to produce any more than 6 or 8 bushels of wheat per acre.

The period from the latter half of the eighteenth century to the middle of the nineteenth century brought great changes in European agricultural methods, especially in England, but I can touch on these changes only briefly in this discussion.

As a result of the enclosures an opportunity was made available for certain changes in English agricultural practice. The preaching of Jethro Tull, the apostle of cultivation, the introduction of root crops and clovers from Flanders, the development of crop rotation, the increase in number of livestock, and the use of animal manures brought about a great increase in crop yields in England.. By 1815, possibly even earlier, wheat yields in England had risen to 20 bushels per acre.

A prime factor in the adoption of these improved methods was the constantly rising prices during the closing decade of the century (2).

The depression that followed the Napoleonic wars, however, kept agricultural improvements at a standstill until the middle of the century.

On the continent in Germany wheat yields rose from 10 bushels per acre in the closing years of the eighteenth century to about 16 bushels by the middle of the nineteenth century (3).

During the same period a like change took place in France with wheat yields increasing from an average of about 12 bushels during the decade following the Napoleonic wars to 16 bushels by the middle of the century (4).

It was not until several years after the publication of the work of Liebig that the revival in the use of improved agricultural methods took place. With Liebig's contribution and the other methods of soil improvement cited above the agricultural revolution went on in northwestern Europe and is now apparently going on in certain parts of the United States where pioneer methods have disappeared.

The history of the crop yield trends of the last 40 or 50 years in various foreign countries, in the United States, and in the various states of the United States, shows the great change in yields that have occurred during the recent period.

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[3] Reference by number is to "Literature Cited," p. 106.

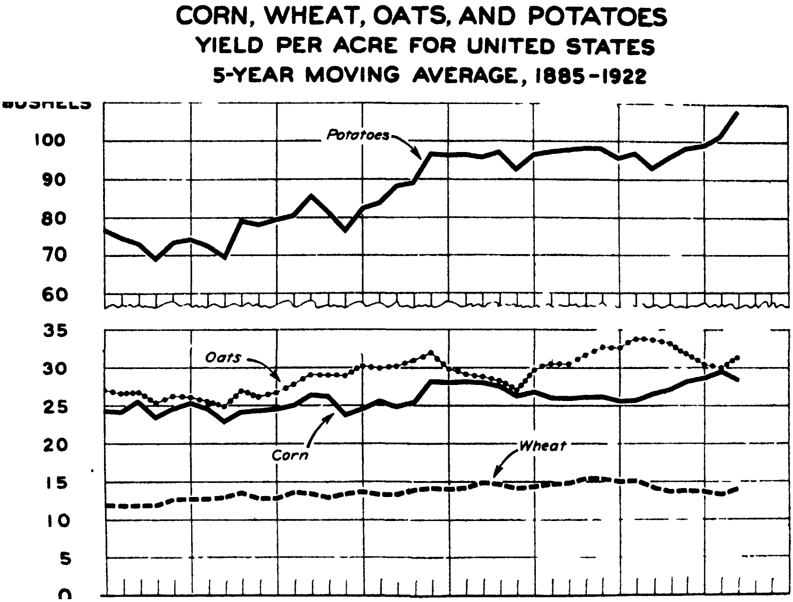

FIG. 1.—There has been a general upward trend in yield per acre of these crops. The decline in wheat yields after 1916 was due in great part to the expansion of the wheat area into the drier portions of the West.

CROP YIELDS IN THE UNITED STATES

Table 1 and the accompanying chart (Fig. 1) show the trend in yield per acre in the United States from 1885 to date for corn, wheat, oats, and potatoes. A moving average has been used to smooth the sharp variations that occur from year to year, principally as a result of climatic effects.

Notwithstanding an enormous increase in acreage of these crops during the period covered by the data, the yields indicate a general upward trend. The increase in harvested acreage for these crops is as follows:

Crops	Average acreage, 1885–89	Average acreage, 1920–24	Percentage increase
Corn	75,042,000	103,524,000	38
Wheat	36,819,000	60,205,000	64
Oats	25,365,000	42,442,000	67
Potatoes	2,418,000	3,877,000	60

A considerable part of this expanded acreage, especially in the case of wheat, was on soils that produced yields below the national average for that crop.

The average yields for the last five years compared with those of the base period show a rise of 4 bushels for corn, 2 bushels for wheat, 4 bushels for oats, and about 30 bushels for potatoes. Several times during the period a tendency to declining yields was indicated, but this in all cases was apparently temporary.

The greater changes that have occurred in the yield level of these crops in certain of the older farming regions of the United States are

TABLE 1.—*Five-year moving average for United States for yield per acre of corn, wheat, oats, and potatoes.*

Year	Corn	Wheat	Oats	Potatoes
	Bushels	*Bushels*	*Bushels*	*Bushels*
1885	24.3	11.9	27.0	76.9
1886	24.1	11.8	26.6	74.7
1887	25.5	11.8	26.7	73.0
1888	23.4	11.9	25.3	69.0
1889	24.5	12.5	26.1	72.9
1890	25.2	12.8	26.0	74.0
1891	24.5	12.8	25.5	72.3
1892	22.8	12.9	24.9	69.6
1893	24.1	13.4	26.9	78.7
1894	24.3	12.8	26.1	78.2
1895	24.5	12.8	26.7	79.4
1896	25.0	13.6	27.8	80.4
1897	26.3	13.4	29.0	85.4
1898	26.2	12.9	29.0	81.6
1899	23.8	13.4	28.9	76.5
1900	24.5	13.7	30.3	82.1
1901	25.5	13.3	30.0	83.7
1902	24.8	13.3	30.2	88.2
1903	25.4	13.9	31.0	89.1
1904	28.1	14.1	32.0	96.2
1905	28.0	14.0	29.9	96.3
1906	28.1	14.2	29.2	96.5
1907	27.9	14.9	28.9	96.8
1908	27.6	14.7	28.4	97.1
1909	26.2	14.1	27.1	92.8
1910	26.7	14.4	29.8	96.4
1911	26.0	14.7	30.6	97.2
1912	25.9	14.8	30.5	97.8
1913	26.0	15.4	31.7	98.3
1914	26.1	15.4	32.8	98.2
1915	25.6	15.0	32.7	95.7
1916	25.7	15.1	33.8	96.8
1917	26.4	14.3	33.7	92.9
1918	27.0	13.7	33.2	95.7
1919	28.1	13.8	31.9	98.0
1920	28.5	13.7	30.5	98.9
1921	29.5	13.3	30.0	101.5
1922	28.4	14.0	31.4	108.1

somewhat concealed in these national trends These regional changes will be discussed later

TREND OF CROP YIELDS IN EUROPE DURING RECENT PERIOD

In Europe the effects of the widespread adoption of the improved agricultural methods and the more intensive utilization of the soils are apparent in the trend of crop yields

The record of wheat yields in the various European countries during the last 40 or 50 years (Fig 2 and Table 2) shows the great changes that have occurred All of these countries display a generally rising trend in wheat yields A like rise occurred in the case of the other cereals and root crops

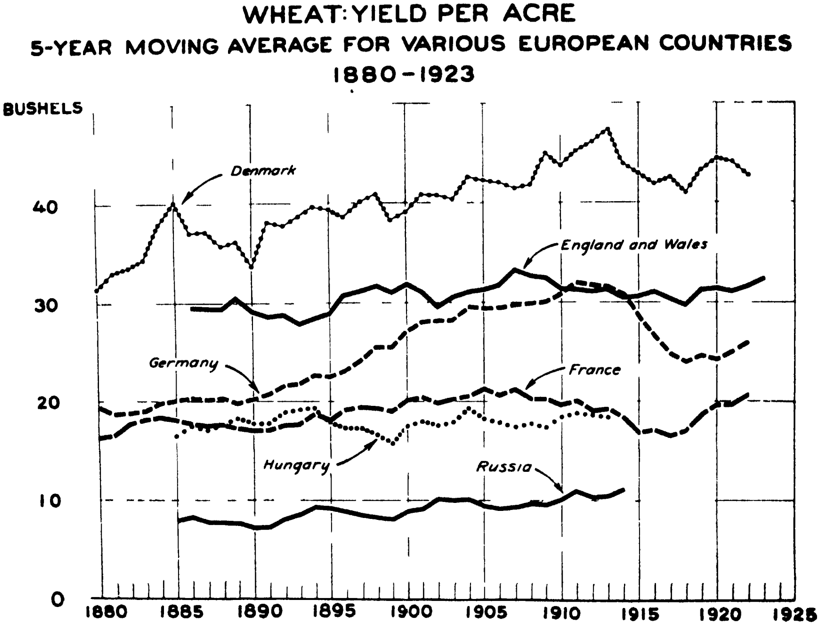

FIG. 2.—There was a general upward trend in the acre-yields of wheat in the various European countries during the past half century. It was not until immediately previous to the outbreak of the World War that Germany attained wheat yields comparable to those of England and Wales War-time conditions caused a sharp fall in wheat yields in both France and Germany In the former recovery has already taken place and in the latter wheat yields are again trending upward.

In England and Wales the rising trend of wheat yields continued until a level of about 32 bushels per acre was reached. During the past 20 years yields have been practically stationary. In Germany wheat yields rose from an average of 19.4 bushels during 1878–82 to

TABLE 2.—*Five-year moving average for various European countries for yield per acre of wheat.*

Year	England and Wales	France	Denmark	Germany	Russia	Hungary
	Bushels	*Bushels*	*Bushels*	*Bushels*	*Bushels*	*Bushels*
1880	—	16.2	31.4	19.4	—	—
1881	—	16.5	32.9	18.7	—	—
1882	—	17.7	33.6	18.8	—	—
1883	—	18.1	34.4	19.0	—	—
1884	—	18.4	37.9	19.8	—	—
1885	—	18.1	40.1	20.0	7.8	16.5
1886	29.6	17.8	37.0	20.3	8.2	17.5
1887	29.5	17.6	37.1	20.1	7.7	17.0
1888	29.4	17.7	35.8	20.3	7.7	17.6
1889	30.3	17.3	36.1	19.8	7.6	18.3
1890	29.1	17.1	35.7	20.2	7.1	17.8
1891	28.6	17.1	38.1	20.7	7.2	17.8
1892	28.8	17.6	37.8	21.6	8.0	18.9
1893	27.9	17.7	38.7	21.7	8.5	19.1
1894	28.4	18.7	39.6	22.6	9.2	19.3
1895	28.9	18.1	39.4	22.4	9.1	17.9
1896	30.7	19.1	38.6	23.0	8.8	17.4
1897	31.1	19.4	40.2	24.1	8.4	17.3
1898	31.6	19.3	40.9	25.4	8.2	16.7
1899	31.0	19.0	38.3	25.4	8.0	15.8
1900	31.8	20.1	39.1	27.0	8.8	17.6
1901	31.0	20.4	40.9	27.9	9.0	18.0
1902	29.6	19.8	40.8	28.1	10.0	17.6
1903	30.5	20.2	40.4	28.2	9.9	17.9
1904	31.0	20.5	42.6	29.6	10.0	19.3
1905	31.3	21.2	42.3	29.4	9.4	18.2
1906	31.7	20.6	42.1	29.5	9.1	17.9
1907	33.1	21.2	41.5	29.7	9.3	17.5
1908	32.6	20.2	41.9	29.9	9.6	17.8
1909	32.4	20.2	45.0	30.0	9.5	17.4
1910	31.4	19.6	43.8	30.8	10.0	18.4
1911	31.2	20.0	45.2	31.9	10.9	18.8
1912	31.0	19.0	46.2	31.7	10.3	18.6
1913	31.2	19.2	47.3	31.5	10.4	18.4
1914	30.4	18.4	43.9	30.8	11.0	—
1915	30.6	16.9	42.9	28.6	—	—
1916	31.0	17.1	41.9	26.6	—	—
1917	30.3	16.5	42.5	24.7	—	—
1918	29.7	17.0	41.0	23.8	—	—
1919	31.1	18.5	43.2	24.5	—	—
1920	31.3	19.6	44.4	24.2	—	—
1921	31.0	19.6	44.1	24.9	—	—
1922	31.5	20.6	42.7	25.9	—	—
1923	32.2	—	—	—	—	—

a level comparable to that in England in the period immediately preceding the World War. In France during the same series of years wheat yields rose from 16 bushels to 20 bushels per acre. As a result of the war-time effects, yields declined in both France and Germany. In the former, recovery to the pre-war level has already taken place. In the case of Germany where wheat yields dropped about 8 bushels below the pre-war level, yields are now again on an upward trend. In Denmark on a comparatively small area wheat yields rose from 31 bushels to over 40 bushels per acre.

In eastern and southeastern Europe where village farming and the practice of fallowing persisted, a slowly rising trend of wheat yields is indicated. The record of wheat yields in Russia for the 30-year period preceding the Russian revolution shows an increase from about 8 bushels to 11 bushels per acre. During that time there was also a great increase of the area in wheat. The rising wheat yields in Russia are claimed to be the result of better cultivation and the use of improved seed on the large Russian estates.

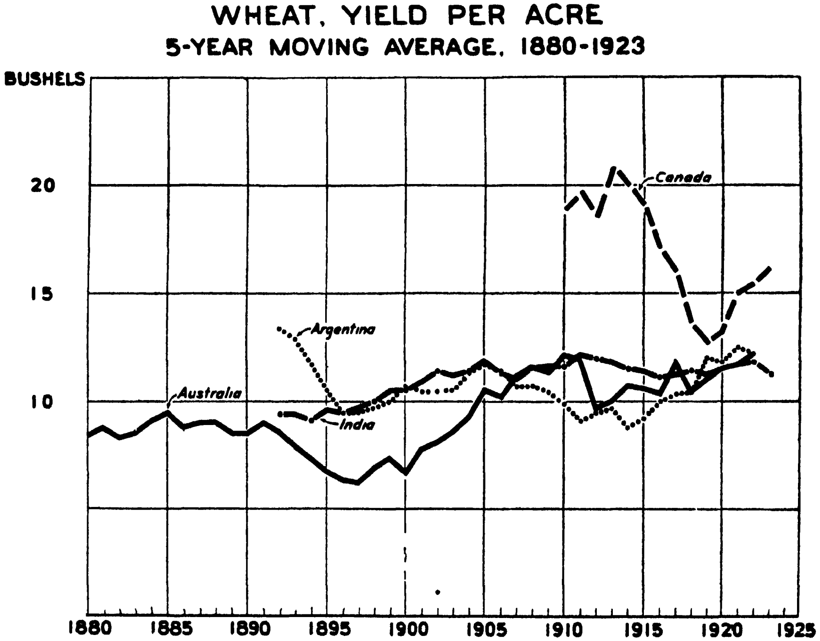

FIG. 3.—During the period of greatest expansion of the wheat area in Australia yields continued to fall. Since the beginning of the 20th century the general trend has been upward. In Canada when the wheat area spread into the drier lands of the West acre yields declined rapidly.

TREND OF WHEAT YIELDS IN OTHER FOREIGN COUNTRIES

Fig. 3 shows the trend of wheat yields in Australia, Canada, Argentina, and India. Extensive production methods still predominate in the grain-growing areas of the first three of these countries.

TABLE 3.—*Five-year moving average for various countries for yield per acre of wheat.*

Year	Australia	Canada	Argentina	India
	Bushels	*Bushels*	*Bushels*	*Bushels*
1880	8.4	—	—	—
1881	8.8	—	—	—
1882	8.3	—	—	—
1883	8.5	—	—	—
1884	9.1	—	—	—
1885	9.5	—	—	—
1886	8.8	—	—	—
1887	9.0	—	—	—
1888	9.0	—	—	—
1889	8.5	—	—	—
1890	8.5	—	—	—
1891	9.0	—	—	—
1892	8.6	—	13.4	9.4
1893	7.9	—	12.9	9.4
1894	7.3	—	11.7	9.1
1895	6.7	—	10.5	9.6
1896	6.3	—	9.5	9.5
1897	6.2	—	9.5	9.7
1898	6.9	—	9.7	10.0
1899	7.4	—	10.0	10.5
1900	6.6	—	10.7	10.5
1901	7.8	—	10.4	10.9
1902	8.1	—	10.4	11.4
1903	8.6	—	10.5	11.2
1904	9.3	—	11.3	11.4
1905	10.5	—	11.7	11.9
1906	10.2	—	11.4	11.3
1907	11.2	—	10.7	11.0
1908	11.6	—	10.7	11.5
1909	11.3	—	10.4	11.6
1910	12.1	18.9	9.9	11.6
1911	12.0	19.7	9.1	12.2
1912	9.7	18.6	9.5	12.0
1913	10.0	20.8	9.7	11.8
1914	10.7	20.0	8.8	11.5
1915	10.6	19.1	9.2	11.4
1916	10.3	17.1	10.0	11.1
1917	11.8	16.0	10.3	11.2
1918	10.4	13.7	10.4	11.4
1919	11.0	12.8	12.0	11.2
1920	11.5	13.2	11.8	11.5
1921	11.7	15.0	12.5	11.8
1922	12.2	15.4	12.2	11.8
1923	—	16.1	—	11.3

In Australia, owing to the expansion of wheat production into areas where the climatic risk was great, yields continued to fall until the closing years of the nineteenth century. Since 1900 the record of wheat yields indicates a rising trend. In certain respects the situation in Argentina and Canada is considerably like that in Australia.

In India the fertility problem has been a serious one for centuries. The small amount of available animal manures and the poverty of the people precluding the use of commercial fertilizers prevent an increase in soil productivity through these channels. The slowly rising trend of wheat yields during the past 35 years is probably the reflection of the educational efforts of the agricultural colleges bringing about somewhat better cultural methods, soil moisture conservation, and the use of improved seed (5).

REGIONAL CHANGES IN PRODUCTIVITY IN THE UNITED STATES AS INDICATED BY CROP STATISTICS

In discussing the trend of yields in the United States, I have hinted at the greater changes that have occurred in certain of the older farming regions during the last half century.

From the beginning of the nineteenth century the westward movement of the frontier of crop production has ever been the focus of national attention Popular conception had it that the soils of the East were worn out and that great stores of soil fertility were to be had only in the new and cheap lands of the West. Farm abandonment in the East was pointed to as evidence of soil deterioration, although the changes brought about as a result of industrial development in the United States may have been factors in making some of this land marginal.

In the East, early in the century, owing to the prevalence of poor and slipshod methods, and on soils that were low in their original store of fertility, crop yields were low. Agricultural writers of this period alluded constantly to the crude methods in vogue (6). By the third or fourth decade changes were becoming apparent and the use of improved methods began to spread in the East. Dr. Falconer (6) describes this period in eastern agriculture as one of soil improvement

With large areas of cheap, new farming lands available in the West, however, it is not to be wondered that progress continued at a very slow rate, and although the benefits to be derived from the use of improved methods were known to many they were practiced by few.

During the latter half of the century, in many areas, especially in the northeastern quarter of the United States, the continued spread in the use of soil improvement methods was showing its effects in the trend of crop yields. Development of suitable rotation systems, more efficient use of animal manures and crop wastes, use of green manures, liming and an increasing use of commercial fertilizers, and use of selected seed brought about a higher level of yields in the areas where these methods were employed.

The statistical record of corn and wheat yields in the various states shows the marked changes that have occurred in the past 40 years.

Over the greater part of the humid portion of the United States for that period the acre yields of these crops indicate a consistent upward trend (Figs. 4 and 5). In certain areas, however, owing to generally poor methods of soil management, yields have remained stationary.

In the states where the crop area spread into the semi-arid region the effect of this expansion can be seen in the lower crop-yield level.

Tables 4 and 5 show the corn and wheat yields by five-year periods during the past 40 years for various states.

The figures indicate that the great outstanding changes have occurred in the Middle Atlantic and East North Central States. Like changes have also occurred in the portions of the West North Central States where pioneer agricultural methods have disappeared. In the case of corn yields a marked rise has taken place in the northern portion of the South Atlantic States. In a general way the sections indicated above, if New England is excluded, comprise the oldest farming regions in the United States.

The averages for the various states during the period covered by the data presented in these tables show the following increases for corn yields: In the North Atlantic States from 6 to 10 bushels; in the East North Central group from 6 to 12 bushels; and in the South Atlantic States (excluding South Carolina, Georgia, and Florida) from 9 to 14 bushels. The five-year averages of the base period compared with the averages during the past five years in Iowa and Minnesota show, respectively, increases of 8 bushels and 6 bushels per acre.

The record of wheat yields for the states included in Table 5 shows a rise of from 5 to 7 bushels per acre in the northeastern portion of the United States. In these states, with few exceptions where a decrease occurred in the wheat area, the acreage in this crop has remained stationary. In Ohio and other states in the Ohio Valley a marked decrease occurred in the average wheat yields for the period 1920–24. This occurred largely as a result of unfavorable weather conditions during the years 1920–22 inclusive. The decrease I believe is only temporary and with normal weather conditions a recovery to the higher level will probably take place. In Kansas, in spite of the

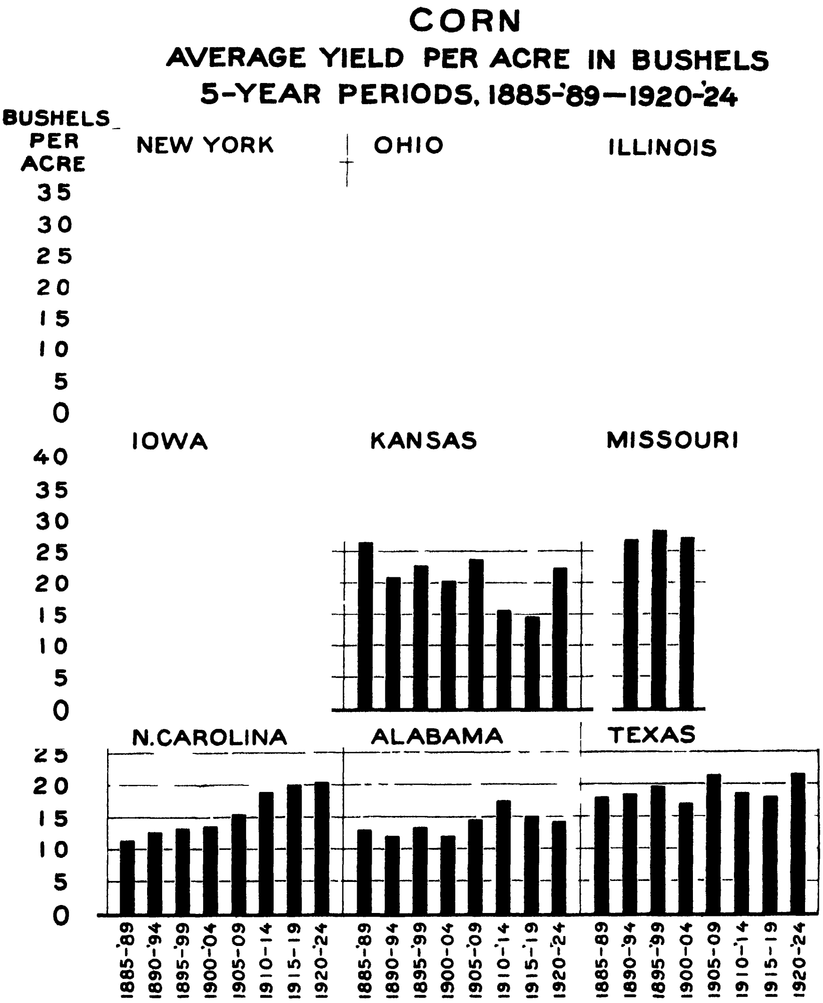

FIG. 4.—Outstanding changes have occurred in the level of corn yields during the past four decades in the northeastern portion of the United States. In the northern portion of the South Atlantic States (Maryland, Virginia, and North Carolina), the rise in the level of corn yields has been relatively even more marked than in northeastern United States.

expansion of the wheat area into the semi-arid portion of the state, yields have remained stationary for the entire period. Wheat yields in Missouri have also remained at a low level, but considering the entire period yields have been stationary. In the spring wheat region pioneer methods and the continued expansion of the wheat area has kept yields at a low level.

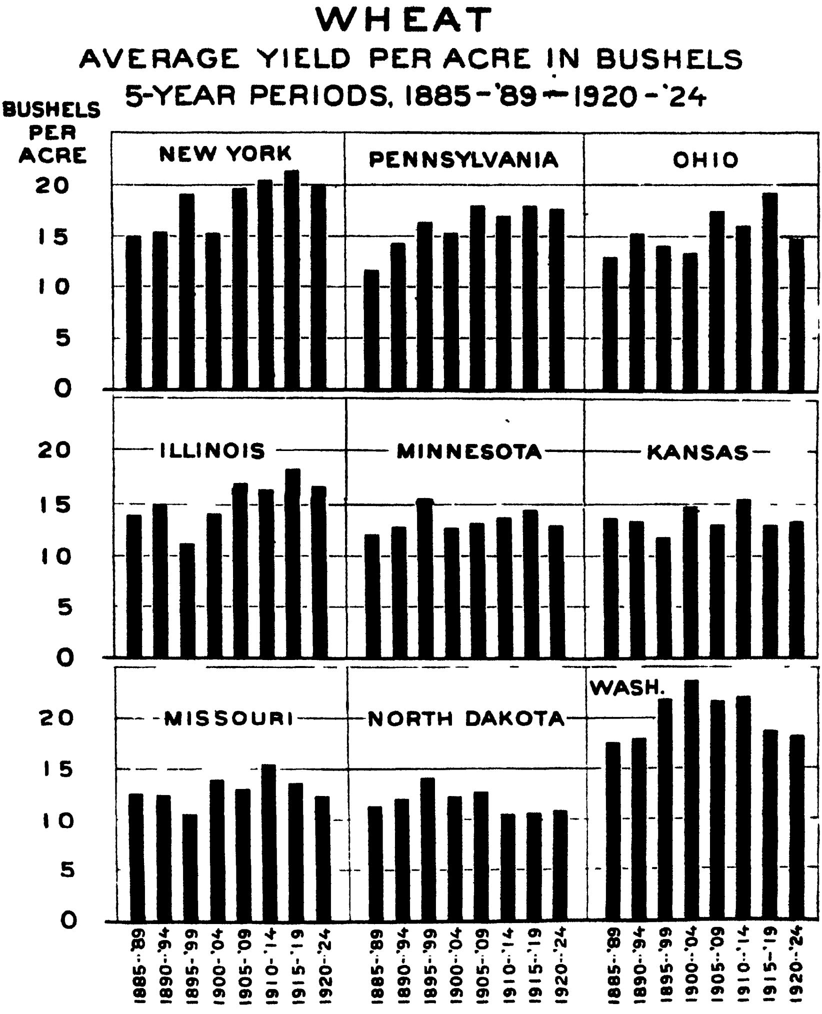

FIG. 5.—As in the case of acre-yields of corn, the trend in wheat yields in northeastern United States (New York, Pennsylvania, Ohio, etc.) has been generally upward, Yields in Kansas have been practically stationary. The fall in wheat yields in Washington since 1900–04 is said to be a result of the expansion of the wheat area into the drier portions of the state.

In certain cases marked differences in their respective crop yields per acre occur in closely associated areas that have somewhat comparable physical conditions. A striking example of this is found in southwestern Iowa and northeastern Kansas. At the beginning of the period (Fig. 6) corn yields were at practically the same level in both of these areas. In southwest Iowa yields rose steadily until in

TABLE 4.—*Average yield of corn per acre by five-year periods 1885–89 to 1920–24 for selected states.*

State	1885–89 *Bushels*	1890–94 *Bushels*	1895–99 *Bushels*	1900–04 *Bushels*	1905–09 *Bushels*	1910–14 *Bushels*	1915–19 *Bushels*	1920–24 *Bushels*
New York	31.3	29.8	32.9	28.3	33.5	37.0	35.9	37.5
New Jersey	30.4	31.4	34.6	33.3	35.8	37.8	40.2	41.4
Pennsylvania	31.0	29.6	35.7	32.4	36.3	41.9	40.8	42.6
Ohio	31.6	27.0	35.9	32.6	38.8	38.9	38.1	38.2
Illinois	28.7	28.1	35.0	33.1	36.5	33.6	35.0	34.7
Wisconsin	27.6	27.2	34.4	30.6	35.6	37.2	33.1	39.2
Minnesota	29.1	25.3	30.5	27.0	31.3	35.3	33.3	34.8
Iowa	31.9	29.2	35.0	31.0	34.5	36.5	36.2	40.2
Kansas	26.5	20.9	22.7	20.3	23.8	15.7	14.6	22.4
Missouri	27.8	26.8	28.3	27.2	30.1	26.2	26.2	29.3
Maryland	22.8	23.2	30.9	31.0	34.1	35.3	37.7	37.7
Virginia	16.0	18.1	20.0	21.1	23.9	24.0	27.9	26.7
North Carolina	11.3	12.7	13.3	13.6	15.6	19.0	20.0	20.5
Alabama	13.1	12.1	13.5	12.1	14.7	17.5	15.0	14.3
Texas	18.1	18.5	19.8	17.1	21.5	18.8	18.2	21.6

TABLE 5.—*Average yield of wheat per acre by five-year periods 1885–89 to 1920–24 for selected states.*

State	1885–89 *Bushels*	1890–94 *Bushels*	1895–99 *Bushels*	1900–04 *Bushels*	1905–09 *Bushels*	1910–14 *Bushels*	1915–19 *Bushels*	1920–24 *Bushels*
New York	15.0	15.4	19.0	15.2	19.6	20.4	21.3	19.8
Pennsylvania	11.6	14.2	16.3	15.3	17.9	16.9	17.9	17.6
Maryland	11.4	13.7	16.3	15.4	16.8	16.5	15.6	16.5
Ohio	12.9	15.3	14.0	13.3	17.4	16.0	19.2	14.8
Illinois	13.9	14.9	11.2	14.1	16.7	16.1	18.1	16.4
Minnesota	12.1	12.8	15.3	12.7	13.2	13.7	14.5	12.9
Kansas	13.7	13.4	11.8	14.7	13.1	15.4	13.0	13.4
Missouri	12.5	12.4	10.5	13.9	13.0	15.4	13.6	12.3
North Dakota	11.3	12.0	14.1	12.2	12.7	10.5	10.6	10.8
Washington......	17.5	17.9	21.8	23.6	21.6	22.0	18.6	18.1

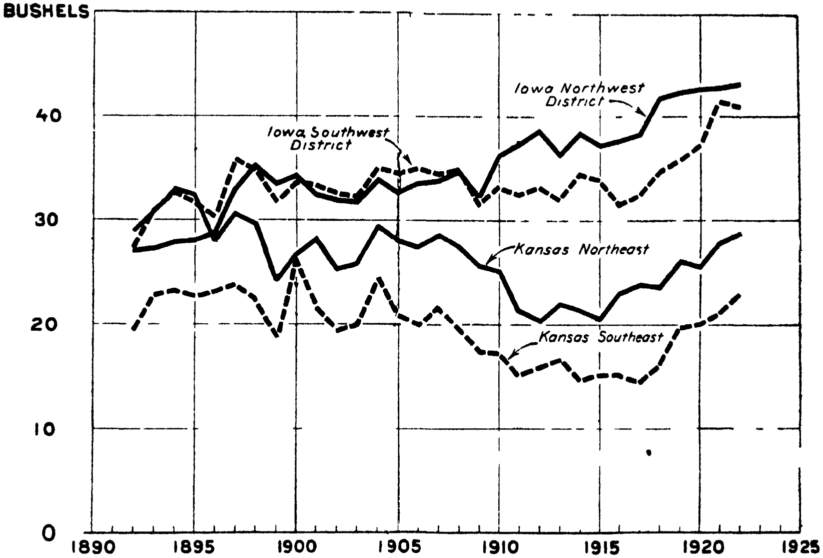
CORN, YIELD PER ACRE
5-YEAR MOVING AVERAGE FOR SELECTED REGIONS
IN IOWA AND KANSAS, 1892-1922

FIG 6 — The two Iowa areas indicated are the northwest and southwest crop reporting districts of the state. The curve for northeast Kansas is based on corn yield data of Nemaha, Brown, Doniphan, Atchison, and Jackson Counties. The curve for southeast Kansas includes the twelve prairie counties of southeastern Kansas.

recent years a difference of about 10 to 12 bushels per acre prevailed in the respective corn yields of these areas The trend in the other two districts shown in the chart has been quite like that in the two areas discussed above Those who have given some study to this condition claim that the explanation is to be found in the prevailing agricultural practices of these areas. Others state that the differences in the character of the soils of southwestern Iowa and northeastern Kansas are great enough to account for the large part of these differences in yields. However, at least part of the difference in the trend in yield per acre of corn in the two localities is due to developments in agricultural practices in Iowa during the period under consideration.

CONCLUSIONS

It appears then in so far as indicated by crop yield statistics:

First, that both on soils employed for many centuries as in various European countries and on soils used for a relatively much shorter period as in the United States the history of crop yields does not indicate any decline in the product per acre. Indeed, indications are that as a result of many factors soils are today more productive than they were formerly.

Second, that on soils with a supply of virgin or acquired fertility, under extensive or crude methods, crop yields will at first decline and ultimately reach a stationary state usually at a low yield level.

Third, that by better cultivation, development of suitable rotations, efficient utilization of crop wastes and animal manures, and the use of commercial fertilizers, poor and low yielding soils can be greatly improved and made more productive.

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IB. THE TESTIMONY OF THE FIELD EXPERIMENTS OF THE COUNTRY[1]

C. G. WILLIAMS[2]

One does not need to have a very wide acquaintance with agricultural conditions to become aware that there is such a thing as soil deterioration. The purpose of this paper is to take note of what some of the field experiments of the country have to say about it.

ROTHAMSTED EXPERIMENTS

Quite naturally the long-continued work at Rothamsted, England, claims one's first attention. Table 1 gives the testimony of Broadbalk and Hoos Fields.

Attention should perhaps be called to the quite marked depression in yield of wheat which appears in the third 10-year period. Each of

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[1] Paper read as a part of the symposium on "Soil Deterioration" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] Director, Ohio Agricultural Experiment Station, Wooster, O.

TABLE 1.—*Average annual yields by 10-year periods of crops grown in continuous culture at Rothamsted.*

Plat No.	Pounds of fertilizing elements applied annually per acre			Period and average annual yields in bushels per acre						
	N	P	K	1	2	3	4	5	6	7
				Wheat, Broadbalk Field						
3	0	0	0	15.9	14.5	10.4	12.6	12.3	10.9	9.1
6	43	29	83	27.2	25.7	19.1	24.5	23.1	21.4	16.6
7	86	29	83	34.7	35.9	26.9	35.0	31.8	31.0	23.2
8	129	29	83	36.1	40.5	31.2	38.4	38.5	37.2	27.4
2[a]	200	34	195	34.2	37.5	28.7	38.2	39.2	34.7	27.0
				Barley, Hoos Field						
1-O	0	0	0	22.4	17.5	13.7	12.7	10.0	9.3	12.1
4-A	43	29	83	46.1	46.4	41.0	40.7	36.3	38.4	36.3
7-2[a]	200	34	195	45.0	51.5	50.2	47.6	44.3	44.3	22.7

[a] Manure.

the five plats shows a decided advance in yield in the fourth and fifth period over the third. This may mean that the last period shown—the seventh—which is exceptionally low in comparison with preceding periods, may be followed by larger yields.

Without placing too much emphasis upon the seventh period it is well to note that the fifth and sixth periods are lower in yield than the first on three of the five plats reported, and that it is not until the annual application of nitrogen amounts to 129 pounds per acre that the reverse is true.

The evidence from Rothamsted continuous wheat is that yields deteriorate quite steadily without the use of manure and fertilizers, and that with less than an annual application of 600 pounds of sulfate of ammonia the yield is not maintained.

Continuous barley at Rothamsted tells substantially the same story. A steady decline in the unfertilized yield from the first to the sixth 10-year period, with a turn upward in the seventh period.

TABLE 2.—*Average annual yields by 10-year periods of crops grown in continuous culture at Woburn.*

Plat No.	Pounds of fertilizing elements applied annually per acre			Period and average annual yields in bushels per acre			
	N	P	K	1	2	3	4
				Wheat			
1–7	0	0	0	17.1	13.6	9.7	9.0
6	25	23	23	32.4	30.1	23.6	—
11-B[a]	164	30	50	26.7	27.8	24.0	—
				Barley			
1–7	0	0	0	24.9	17.5	12.5	9.2
6	25	23	23	46.0	41.1	35.3	—
11-B[a]	164	30	50	40.0	39.9	36.6	—

[a] Manure.

WOBURN EXPERIMENTS

At Woburn the unfertilized continuous wheat declines each 10-year period without exception. The fertilized wheat also declines, and the manured wheat, barring a slight increase in the second period. The fourth period is omitted in the treated plats because of a change in treatment.

OHIO EXPERIMENTS

In the Ohio experiments in growing wheat continuously only 30 years' work has been completed. In the light of the Rothamsted experiments this would seem to be too short a time to give the final answer.

TABLE 3.— *Average annual yields by 10-year periods of crops grown in continuous culture in Ohio.*

Plat No.	Pounds of fertilizing elements applied annually per acre			Period and average annual yields in bushels per acre		
	N	P	K	1	2	3
			Wheat			
1–4 7–10	0	0	0	9.2	5.8	6.7
2	25	11.2	41	20.8	17.3	19.3
3	25	3.1	12	16.6	14.0	14.3
8	50	11.2	41	23.0	21.5	22.8
9	50	6.3	24	22.2	19.6	20.5
6[a]	50	13.0	42	17.1	18.1	21.4
			Oats			
1–4 7–10	0	0	0	24.3	20.0	17.2
2	25	11.2	41	41.2	40.0	37.0
3	25	3.8	21	37.6	35.8	34.1
8	50	11.2	41	48.8	44.3	44.9
9	50	7.7	41	47.1	42.2	43.1
6[a]	50	13.0	42	35.8	39.0	32.6
			Corn			
1–4 7–10	0	0	0	21.5	9.4	9.1
2	25	11.2	41	45.9	37.4	33.3
3	25	4.2	12	39.0	27.4	26.7
8	50	11.2	41	48.5	45.2	38.0
9	50	8.4	24	46.4	41.8	34.3
6[a]	50	13.0	42	41.6	32.4	27.5

[a] Manure.

Arranging the data in three 10-year periods, it will be noted that four of the six plats of wheat yielded less the last period than the first; one practically the same; while the plat receiving stable manure made steady gains from start to finish, though it is yielding no more in the third 10-year period than plats 8 and 9 which started out considerably higher, probably owing to the greater availability of the commercial fertilizers.

In the work with oats the decline in yield of the unfertilized plats is quite regular, as also most of the treated plats. In every instance the average yield of the last 10 years is lower than the first 10 years.

In the continuous corn experiments, without a single exception, the yield of each succeeding 10-year period is lower than the preceding period.

MISSOURI EXPERIMENTS

In the Missouri experiments with continuous wheat the unfertilized plat yields lower in the third 10-year period than in the first, while the fertilized and manured plats yield higher.

The unfertilized oats improve in yield, as also the manured plat.

There is a decided reduction in yield in both the unfertilized and manured corn. As in the Ohio work the yield of corn decreases rapidly, with or without treatment.

TABLE 4.—*Average annual yields by 10-year periods of crops grown in continuous culture in Missouri.*

Plat No.	Pounds of fertilizing elements applied annually per acre			Period and average annual yields in bushels per acre		
	N	P	K	1	2	3
			Wheat			
9	0	0	0	9.6	11.1	7.7
2	68	12	38	15.4	21.2	17.0
10[a]	53	14	44	16.9	17.4	17.6
			Oats			
16	0	0	0	17.0	13.8	19.7
15[a]	53	14	44	25.8	27.2	28.6
			Corn			
17	0	0	0	28.4	17.2	16.6
18[a]	53	14	44	43.3	32.9	25.0

[a] Manure.

ILLINOIS EXPERIMENTS

In the older plat work of the Illinois station the unfertilized continuous corn declines from 40.9 bushels per acre as an average of the first 10 years to 28.3 bushels, the average of the third 10 years.

In a two-year rotation of corn and oats the unfertilized yields of corn are 42.5 bushels for the first period and 37.6 bushels for the third.

In a three-year rotation of corn, oats, and clover the unfertilized yields of corn are 52.1 bushels for the first period and 40.7 bushels for the third.

ENGLISH AND AMERICAN SUMMARY

There is fairly consistent agreement in the unfertilized continuous wheat in these widely separated tests. In the manured wheat

TABLE 5.—*Wheat grown in continuous culture.*

	Period and average annual yields in bushels per acre		
	1	2	3
	Unfertilized		
Rothamsted[a]	12.3	10.9	9.1
Woburn[a]	13.6	9.7	9.0
Ohio	9.2	5.8	6.7
Missouri	9.6	11.1	7.7
	Manured		
Rothamsted[a]	39.2	34.7	27.0
Woburn	26.7	27.8	24.0
Ohio	17.1	18.1	21.4
Missouri	16.9	17.4	17.6

[a] Last 3 periods.

there appears to be disagreement. It amounts to this, however, that where the yield started high an application of 150 to 200 pounds of nitrogen annually has about maintained the yield. With a low yield at the start the yield has slightly increased.

ROTATION FERTILITY TESTS

PENNSYLVANIA

Taking up the four-year rotation fertility work of the Pennsylvania Station as reported in Bulletin 175, and arranging the data in five periods of eight years (two rotations) each, using the valuations given by the Pennsylvania Station, the average annual crop values per acre given in Table 6 are found.

TABLE 6.—*Average annual values by periods of crops grown in rotation in Pennsylvania.*

Plat No.	Pounds of fertilizing elements, average annual application			Period (8 years) and average annual value per acre				
	N	P	K	1	2	3	4	5
1	0	0	0	$22.06	$17.92	$12.51	$11.51	$11.17
7–15								
25–29	0	10.5	20	26.85	30.35	25.98	27.88	27.12
26	12	10.5	20	29.80	30.68	27.17	30.18	30.14
27	24	10.5	20	30.16	31.26	28.72	31.24	30.87
28	36	10.5	20	30.14	31.87	28.55	31.64	31.65
16[a]	29	8.3	21	28.51	29.58	27.42	29.48	28.82
18[a]	39	11.1	29	28.47	29.88	28.24	30.02	30.36
20[a]	49	14.0	36	28.04	30.28	29.95	32.44	33.44

[a] Manure.

It will be noted that plat 1, unfertilized, has declined in production from the first to the fifth period, the last being almost exactly one-half the production of the first period.

Plats 7, 15, 25, and 29, which receive phosphorus and potassium, have maintained a surprisingly uniform production, completing the fifth period about as they began.

The plats receiving a so-called complete fertilizer with varying amounts of nitrogen derived from nitrate of soda have all made slight increases in production.

The plats receiving stable manure have also increased in yield. In the first two rotations they produced less than those receiving commercial fertilizer, but the plat receiving 10 tons of manure (20) is in the lead in the last period.

OHIO

Thirty years' work with the five-year fertility rotation at the Ohio station is reported in periods of 10 years each in Table 7.

TABLE 7.—*Average annual values by 10-year periods of crops grown in five-year rotation in Ohio.*

Plat No.	Pounds of fertilizing elements applied annually per acre			Period and average annual value per acre		
	N	P	K	1	2	3
1–28	0	0	0	$16.42	$15.79	$12.32
	Same plus lime				19.29	19.47
8	0	4	22	22.47	25.03	21.43
	Same plus lime				32.75	37.46
11	15	4	22	27.03	30.06	26.68
	Same plus lime				36.75	40.74
17	7.5	6	22	24.52	29.03	26.72
	Same plus lime				37.61	41.21
18[a]	30	8	25	25.38	33.20	30.78
	Same plus lime				41.09	43.50
20[a]	15	4	12	22.31	25.95	22.38
	Same plus lime				33.99	36.24

[a] Manure.

At the end of the first 10 years' work one-half of all the plats was limed, and regularly thereafter every 5 years. For the second and third 10-year periods the production is reported for both the limed and unlimed plats. It should be stated that at the beginning of this test clover was growing fairly well without liming, but gradually began to fail.

Taking into consideration the continuously unlimed plats, it will be noted that the unfertilized plats (the figures are the average for 10 plats) decline in production from one period to the next; that neither plats 8 nor 11 quite maintain their production; that plat 17 with less nitrogen but more phosphorus than plat 11 does a little more than maintain its production; and that plat 18 (manure) makes a decided gain, while plat 20, with one-half the manure, holds its own.

When the limed half of these plats is considered a different story is told. Not only is there a decided increase in production the second period as compared with the first, but the third 10-year period is greater than the second. The unfertilized plats go from $16.42 to $19.47; the phosphorus-potassium plats from $22.47 to $37.46; the nitrogen-phosphorus-potassium plats from $27.03 to $40.74; the low-nitrogen-high-phosphorus-potassium plats from $24.52 to $41.21; and the manured plat (18) from $25.38 to $43.50.

I should also like to call attention to two three-year rotations at the Ohio station. One is a rotation of corn, wheat, and clover which has been in operation 27 years.

TABLE 8.—*Average yields of grain in bushels per acre for nine-year periods in rotation experiments in Ohio.*

	1897 1905	1906–1915	1915–1924
Corn			
Plat 6, acid phosphate and manure. . .	62.28	71.80	70.85
Average unfertilized	36.99	33.23	39.44
Wheat			
Plat 6, acid phosphate and manure. .	25.26	28.87	32.44
Average unfertilized	9.92	13.81	18.75
Clover hay, pounds			
Plat 6, acid phosphate and manure. . . .	4,341	5,414	5,254
Average unfertilized	2,030	3,421	3,675

The data presented in Table 8 are arranged in three periods of nine years each (three full rotations to each period). Beginning with the close of the first period, *all* of the plats have been limed regularly. The yield of corn on the unfertilized plats averaged 36.99 bushels per acre the first period and 39.44 bushels the third period, a gain of 6.6%. The wheat crop averaged 9.92 bushels the first period and 18.75 bushels the third, a gain of 89%. The clover hay averaged 2,030 pounds per acre for the first period and 3,675 pounds for the third, a gain of 81%.

Similarly, plat 6 which received 8 tons of manure and 320 pounds of acid phosphate on each corn crop gave a yield of 62.28 bushels of corn per acre the first period and 70.85 bushels the third, a gain of 14%. A yield of 25.26 bushels of wheat was made the first period and 32.44 bushels the third, a gain of 28%; and a yield of 4,341 pounds of clover hay the first period and 5,254 pounds the third, a gain of 21%.

The other three-year rotation is one of corn, oats, and clover, which has been in operation 20 years. Data on yields are given in Table 9.

TABLE 9.—*Average yield in bushels per acre of nine plats arranged in six-year periods for unfertilized and unlimed plats in Ohio.*

1	2	3
	Corn	
57.70	38.43	31.39
	Oats	
51.90	33.60	37.27
	Clover hay, pounds	
4,673	2,245	1,621

LIME AND FLOATS TEST

A very different condition prevails here. When this experiment was started the land was in a very productive state, yielding upward of 70 bushels of corn per acre, 55 bushels of oats, and 5,000 pounds of clover hay. As an average of the first two rotations (six crops), the yield of corn on the unfertilized plats was 57.7 bushels per acre, which without lime has declined to 31.39 bushels (a six-year average) in the third period, a loss of 45%. The yield of oats has declined from 51.9 to 37.3 bushels, a loss of 28%, and the yield of clover from an average of 4,673 pounds per acre to 1,621 pounds, a loss of 65%.

The shifting in the yield of corn from a gain of 6.6% in the first rotation to a loss of 45% in the second and from a gain of 81% to a loss of 65% in the clover crops is to be explained in the main by the use or non-use of lime. It should be stated, however, that the use of lime alone was not able to maintain the high level of production at which the second test started; though with lime alone the two tests are yielding at about the same rate at the present time, one having declined from a higher yield and the other having advanced from a lower. This is shown in Table 10.

TABLE 10.—*Effect of lime on yield of corn and clover hay in Ohio.*

	1	2	3
Corn yields, bushels per acre			
In manure test, average of eight plats.	36.99	33.23	39.44
In lime and floats test, plat 14.	61.33	50.31	37.51
Clover hay, pounds per acre			
In manure test, average of eight plats.	2,030	3,421	3,675
In lime and floats test, plat 14.	4,880	3,462	3,566

Continuous cropping without any treatment.

Rothamsted continuous wheat declined	42% in yield in 60 years
Rothamsted continuous barley declined	58% in yield in 50 years
Woburn continuous wheat declined	47% in yield in 30 years
Woburn continuous barley declined	63% in yield in 30 years
Ohio continuous wheat declined	27% in yield in 20 years
Ohio continuous oats declined	29% in yield in 20 years
Ohio continuous corn declined	57% in yield in 20 years
Missouri continuous wheat declined	20% in yield in 20 years
Missouri continuous corn declined	41% in yield in 20 years
Missouri continuous oats gained	16% in yield in 20 years
Illinois continuous corn declined	30% in yield in 20 years

Ohio five-year rotation fertility work.

Without treatment production declined	25% in 20 years
With lime production increased	18% in 20 years
With lime and P production increased	18% in 20 years
With lime, P, and K production increased	66% in 20 years
With lime, P, K, and N production increased	50% in 20 years
With lime, P, K, N (plat 17) production increased	68% in 20 years
With lime and manure (plat 18) production increased	71% in 20 years

Pennsylvania four-year rotation fertility work.

Without treatment production declined	49% in 32 years
With P and K production increased	1% in 32 years
With P, K, N (plat 28) production increased	5% in 32 years
With manure production increased	19% in 32 years

Ohio three-year rotation (manure test).

With lime but no other treatment	The yield of corn increased	6.6% in 18 years
	The yield of wheat increased	89.0% in 18 years
	The yield of clover increased	81.0% in 18 years
With lime, manure, and acid phosphate	The yield of corn increased	14.0% in 18 years
	The yield of wheat increased	28.0% in 18 years
	The yield of clover increased	21.0% in 18 years

Ohio three-year rotation (lime and floats test).

Without lime or fertilizer	The yield of corn decreased	45% in 12 years
	The yield of oats decreased	28% in 12 years
	The yield of clover decreased	65% in 12 years

SUMMARY

1. The more productive the soil the more rapid will be the deterioration without treatment. (Compare Rothamsted and Woburn continuous wheat and barley and Ohio and Pennsylvania rotations.)

2. Production declines more rapidly with some crops than others. (Compare Ohio and Missouri continuous oats and corn and Rothamsted and Woburn wheat and barley.)

3. Rotation of crops, including clover, has not maintained production without treatment. (See Illinois, Pennsylvania, and Ohio.)

4. Though three times as much plant food has been applied in continuous culture as in rotation farming, it has not produced as large a gross return. (See plat 8 in Ohio continuous tests and plat 17 in five-year rotation tests.)

5. Lime alone in a short rotation in which clover is grown will, under some conditions, maintain production at a moderate or low level of production. (See Table 8.)

6. Manure, acid phosphate, and lime have maintained for 27 and more years a yield of 70 bushels of corn, 30 bushels of wheat, and 5,000 pounds of clover. (See Table 8.)

2A. CHANGES IN CHARACTER, CONDITION, AND AMOUNT OF SOIL ORGANIC MATTER[1]

OSWALD SCHREINER[2]

It has been the natural process for a soil to increase in fertility, and this accumulation, although slow, has been going on throughout the ages of soil formation, long before man appeared to wrest therefrom his food and raiment. It is only when man interferes with these natural methods of accumulation that soil deterioration sets in. Viewing the soil as a whole, we must conclude that it is the product of its environment. In the beginning, when all was chaos and void, the all sustaining soil was not. We are all agreed that its formation is the result of the action of the water and air upon the rocks of the earth. Mere rock powder, however, is not fertile soil. The accumulations of fertile soils, which now feed the nations of the earth and clothe them and supply them with the products of field and forest in an industrial development unprecedented in history, was made possible by the development of organic life within the soil, aiding in the action of water on the rocks, in the action of air in furthering decomposition, and in living and in dying adding to the store of organic matter in the soil. Thus from the most primitive life forms, up through the ages, soil has been formed, through the interaction of organic life, air, water, and rock.

As time went on, with each generation of living forms the store of what we now call available food was augmented, since the original rock of the earth contains but little water-soluble or available plant food as compared with the fertile soils of our agricultural domains. These fertile soils are therefore the accumulations of rock and organic detritus, and have in a measure come to be in equilibrium, in each environment, with the climatic and vegetative factors which formed them. This equilibrium is a dynamic equilibrium and not a static one, but it is nevertheless, by and large, an equilibrium, which determines the natural inherent factors of soil fertility or of crop productiveness.

It behooves us to consider at this point that if the occupation of the land by man decreases the soil fertility or productiveness it must be through the influence which he exerts on this equilibrium between earth, water, and sky which constitutes the soil. To discuss this fully would lead me much astray from the topic assigned to me, namely, the influence of organic matter in soil deterioration, but I must say in passing that the chances of man changing permanently the age-old product of these natural forces is remote indeed and that such small influence as he will exert by his occupation and control of the land is most likely to be in the factor most susceptible to change. This factor lies obviously in the organic matter of the soil. Everyone of you knows how rapidly organic plant debris, stable manure, and the like disappears when put into the soil; a year or two at most and it has vanished as compared with the almost everlasting permanence of the mineral parts of the soil. It is true that the soil can be robbed of its store of available and soluble mineral plant food constituents by the carrying away of the crops from the land, but this so-called robbery is small, statistically almost insignificant, in comparison with the natural processes which have brought the fertility of the soil to its present state of dynamic equilibrium with its climatic environment.

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[1] Paper read as a part of the symposium on "Soil Deterioration" at the meeting of the Society held in Chicago, Illinois, November 16, 1925.

[2] Senior Biochemist in charge, Soil-Fertility Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

The oldest soils agriculturally occupied by man are still producing crops and in chemical composition are not unlike our newly occupied soils. That crop yields from a national and world viewpoint are not decreasing seems to be shown by statistical methods; in fact, the application of scientific agriculture in improved seeds, disease control, as well as in the upbuilding of soil fertility through the intelligent use of fertilizers and crop rotation, including the use of green manures to augment the store of organic matter and nitrogen and advance those biochemical changes of which I am going to speak, is beginning to show itself, and will continue to show itself more and more, as these means of increasing the soil's productivity and its fertility, come more and more into general use throughout the world.

No fertile soil has yet been found in nature which was devoid of organic life or products of organic decay, in short, devoid of soil humus or organic matter. It may vary from extremely small amounts in infertile sands to extremely large amounts in equally infertile peats, but in the great mass of normal fertile soils in the agricultural regions of the world its presence and its amount has always been indicative of the soil's fertility.

It is almost axiomatic in agriculture that increasing the soil's store of organic matter means increase of fertility, and decrease in the soil's organic matter means decreased fertility. There may be some among you as agronomists who have a reasonable doubt of the efficacy of commercial fertilizers in your region, but there are few, if any, who would hestitate to recommend in any soil-upbuilding program the introduction of organic matter as manure or plant residues, or green crops plowed under, especially legumes, or hestiate to advise crop rotation so as to obtain these benefits. To quote only one authority, our Nestor of scientific farming in America, Director Thorne (1)[3] of Ohio, who in an article dealing with soil deterioration says, "Scattered throughout this region are many farms that are today producing larger crops than when first reclaimed from forest or prairie, and whose rate of production is steadily increasing; and when we study the method by which the fertility of these farms has been maintained we find that it has been based upon conservation and increase of the humus supply, a method as old as agriculture, and yet its importance is so seldom realized, and the means of employing it so imperfectly understood, that the prevailing tendency of agriculture is towards the steady depletion of this supply." This principle of increasing the humus supply is as old as Roman institutions and the earliest records of agriculture devote themselves to this subject as is well known to you.

Two soils which we have had under observation in connection with our pecan orchard fertilizer studies illustrate well what can be done in soil improvement or soil deterioration in a comparatively short time under orchard conditions. This orchard was located on a soil that was unproductive, the result of many years of constant cropping to cotton and corn. No effort was made prior to 1918 to increase the organic matter of the soil and nothing was plowed under except cotton and corn stalks, and whatever forage crops were grown were cut for hay. In 1918 the organic matter content was 1.11% and nitrogen 0.031%. In the following five years there were grown a summer cover crop of some legumes, successively as follows: Cowpeas, beggarweed, cowpeas, velvet beans, velvet beans, and a winter cover crop of small grain, rye, or oats. All vegetative matter produced was plowed under. In five years the physical condition of the soil improved remarkably; there was improvement in the condition and productivity of the trees and the growth of the cover crops showed that general soil improvement had taken place. The organic matter content rose steadily. From 1.11% in 1918 it increased to 1.56% in 1921, 2.13% in 1922, and 2.40% in 1923, more than double the amount before green manuring was practiced. The nitrogen content likewise rose steadily from 0.031% in 1918 to 0.061% in 1923, practically double.

The second orchard, located on a soil normally better than the one underlying the orchard above described, had likewise been cropped to cotton and corn, with little or no vegetable matter returned to the soil and no attention given to soil improvement; even native grasses were cut and sold for hay. A similar program of soil improvement was laid out for this orchard, but it was not followed. In two of the years peas or beans were broadcast between the tree rows, but they had to fight for existence with native grasses and weeds. As before, all vegetation was cut, cured, and sold for hay. The soil was not plowed during the four years of our observation; the most it received was a disking in the spring. Of course, no improvement in tree growth or soil productivity could take place under such farming conditions. In 1918, this soil contained 0.65% organic matter and 0.022% nitrogen. Four years later, in 1922, the organic matter had further decreased to 0.50% and the nitrogen to 0.018%. While these differences are slight, they show nevertheless that this soil is losing ground in its good fight to maintain the fertility and productiveness native to its location and environment while under the control of its present owner; but this is only temporary, for as sure as the sun's course is from east to west the meagre returns from the soil will so impoverish its owner that he will be forced to sell to another, and let us hope, a better farmer who will treat the soil more kindly after the approved methods of agronomy.

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[3] Reference by number is to "Literature Cited," p. 126.

When our chairman asked me to present the evidence which organic matter would throw on soil deterioration, I wrote him that I would do this with the understanding that acceptance did not mean that I believed in the general nation-wide, or world-wide, deterioration of soils as the result of man's occupation. When all the evidence is before us it will be found that from a national or a world point of view there can be no question of deterioration; the big soil areas of agricultural land will be found to be increasing in soil productivity under man's intelligent occupation, not decreasing, and that such soil deterioration as is locally in evidence is due to poor farming methods, misuse and abuse of our God-given heritage.

I would not be misunderstood that I thereby arraign as poor farmers all those who practice these farming methods which lead temporarily to soil deterioration or decreased productivity, since such misuse or abuse of soils is often forced upon the occupying farmer by economic conditions which place him at a disadvantage with more favored fellow farmers elsewhere, but the fact remains that it is possible to influence soil productivity favorably everywhere, though it may not always be possible to do it profitably under existing economic conditions. Hence it is important in furthering national soil improvement, that the cost of draining land, lime, fertilizers, growing green manuring crops, and in fact, the cost of good farming generally, be kept in harmony with the price return the farmer gets for the produce of his soil and toil.

Now what is the evidence that under human occupation soil organic matter deteriorates? Individual cases of this kind can be found in the literature, but the data are meager on the whole and nowhere have the organic changes which take place during this deterioration been traced. More often it has not been the organic matter itself that has been determined, but rather the nitrogen contained therein.

Snyder (2) in Minnesota showed that as a result of growing wheat on the same land for 12 years the nitrogen had been reduced 2,039 pounds or about 26% of that originally found in the soil at the beginning of the test. The crops grown, however, accounted for less than 450 pounds of this nitrogen, showing that nearly 1,600 pounds had been lost, mainly through decay of the soil organic matter under this type of continuous farming. Hopkins (3) of Illinois reports that a plat growing corn for 16 years contained 4,000 pounds and adjoining pasture land 4,914 pounds of nitrogen in the surface soil. Likewise, the Rothamsted (4 and 5) results have shown that in soil kept clear of vegetable growth for 35 years there was a decrease in nitrogen from 3,500 pounds originally present to 2,450 pounds at the end of 35 years. The nitrogen data for the Broadbalk continuous wheat field at Rothamsted likewise furnishes some evidence, although manured. In 1865, the nitrogen per acre was 4,340 pounds and in the course of 47 years there were added to the soil in manure, seed, etc , 9,730 pounds of nitrogen. Of this total amount added, the crop had only removed 2,550 pounds, and the soil showed a gain of 1,390 pounds so that there is shown a total loss of nitrogen from the soil of 5,090 pounds in the 47 years, or an average annual loss of 123 pounds under continuous wheat culture.

These examples content themselves with the nitrogen in the soil, but this may be considered as equivalent to organic matter in this connection. The Pennsylvania (6) long-term experiments with corn, oats, wheat, and grass in rotation furnish an example in which the organic matter itself was determined. The untreated plats decreased in organic content from 1.64% in 1899 to 1.43% in 1921, and the nitrogen from 0.124% to 0.111%.

. The most pertinent figures in this connection are the comparisons of virgin soil and cultivated soil made by Shutt (7 and 8) in Canada and by Alway (9) in Nebraska. The unbroken prairie in Saskatchewan showed 6,936 pounds of nitrogen per acre as compared with

4,736 pounds of nitrogen per acre found after 22 years cultivation. Of this loss 700 pounds were recovered in the crop, leaving a loss of 1,400 pounds of nitrogen or an average annual loss of 68 pounds. Shutt reports 3,780 pounds of nitrogen in virgin and 3,240 pounds in cultivated soil in the Province of Quebec, and 3,160 pounds in virgin as compared with 2,260 pounds of nitrogen in cultivated soil from New Brunswick.

By far the most complete data on organic matter in soils under cultivation is furnished by the work of Alway on Nebraska soils. The organic matter content of the prairie, presumably in equilibrium with its climatic environment, has on the average, been reduced from 4.82% to 3.26% in cultivated fields and the corresponding nitrogen content from 0.234% to 0.177%; or considering all nitrogen determinations made, from 0.242% to 0.187%. One might draw some interesting conclusions from this excellent and pertinent analytical data to show that under human occupation the organic matter decreased and that this decrease was least in the nitrogenous soil constituents, since in the original prairie soil the ratio of nitrogen to organic matter is 1:20, while in the long cultivated soil it is 1:18, if it were not for the fact pointed out by Alway that the greatest losses of organic matter and nitrogen have been caused either by washing or by blowing away of the surface soil, that is, by physical agencies rather than by chemical or biochemical action.

A similar type of data has been reported by Ladd (10, 11, 12, and 13) of North Dakota, Bradley (14) of Oregon, Stewart (15) of Utah, Thatcher (16) of Washington, and others. Stewart found cultivated fields under dry farming conditions to contain more organic matter and nitrogen than adjacent virgin soils, but Thatcher's results do not confirm this for Washington conditions. Thatcher says, "Assuming that the observed differences between adjacent virgin and cultivated lands are due to the effect of the cropping of the land, it may be said that these results show, in general, a significant reduction in the organic constituents of the soil by the present methods of 'dry farming' operations."

There have been undoubtedly many chemical changes in this most reactive and changeable of soil constituents, but this change is not disclosed by this type of analytical chemical or statistical research. I have not been able to find anywhere any data bearing directly on this subject of organic matter changes obtained from soils in which deterioration under human occupation has been definitely established.

In considering these various discussions on soil deterioration as it affects organic matter or as organic matter affects soil deterioration I have become conscious of the continual use of certain expressions which produce a psychological attitude that seems to prevent clear thinking. We use such expressions as "maintaining," "augmenting or increasing," "depleting," etc , the "store of organic matter," or of "humus" and the like in soils, with equivalent terms for "store," or "content of nitrogen in soils," as if the amount of organic matter or of nitrogen in the soil were some fixed quantity placed there at some time in the world's history by a wise Creator to be drawn on by the farmer as he would make a loan.

What we lose sight of is that the organic matter of a soil is approximately fixed in amount only by the environment; a dynamic equilibrium between its destruction and its supply. However, it is not the equilibrium that is the most important factor in soil fertility, but the dynamics that produce the equilibrium. In a fertile soil this organic matter is in a continual change from season to season and on this change depends the very life of the soil and all its fertility-promoting factors, and when organic matter has ceased to change, has become chemically and bacteriologically inert, we have soil infertility. It is the changing organic matter, that makes for soil fertility, not the mere presence or store in the soil Organic matter is in ever-changing flux and flow, and therefore the best methods used for soil improvement since agriculture began lie in imitating nature's continual supply of organic matter to the soil It is only by continually supplying organic matter that the soil-forming, soil-fertility promoting, dynamic changes can continue to go on unchecked and undiminished, liberating ammonia and other compounds, supplying energy for bacterial life and furthering nitrification and nitrogen fixation. During organic decay there are liberated in their most available forms, the plant foods stored in the vegetable and organic remains, and more plant foods from the minerals of the soil are made soluble. In short, the organic matter introduced into the soil, starts up an unending chain of dynamic forces, a veritable industry of activities, which shows itself in increased production of crops as compared with the soil from which organic matter is withheld, the supply diminished, the factory of plant food production shut down. If we would understand soil fertility as influenced by organic manures, green manures, and good farming methods we must study not so much the organic content, except it be as a key to these dynamic factors, but the organic chemical changes themselves which affect soil fertility must be clearly worked out. In this field of research activity much remains to be done, but in the meantime let not our expressions becloud our thinking.

As you know, we have been conducting for some years past a study of soil organic matter in general, from the standpoint of bio-chemistry, a resumé of which will be of interest to you in this connection. I will therefore attempt to give a brief diagrammatic representation of the results of these investigations which will throw some light upon the processes and the changes which organic matter undergoes in soils generally, as well as those which may take place under systems of agriculture where the supply of organic matter of the soil is not being maintained.

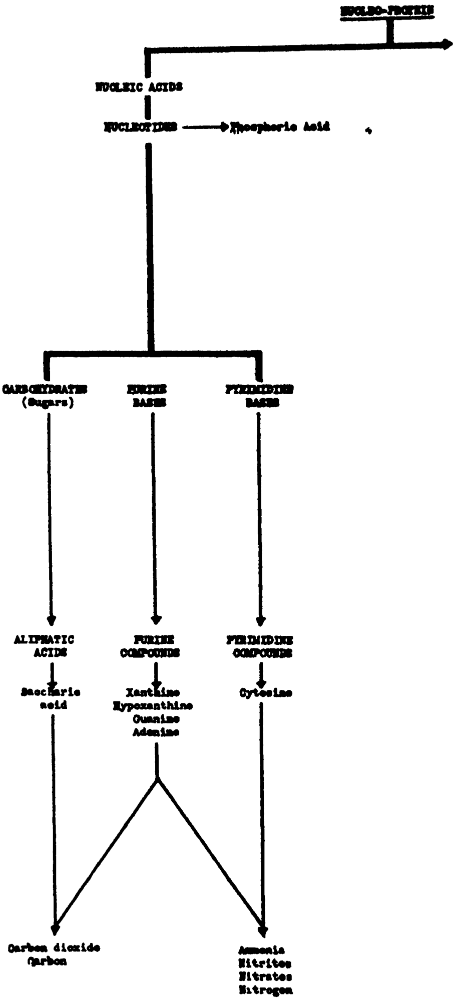
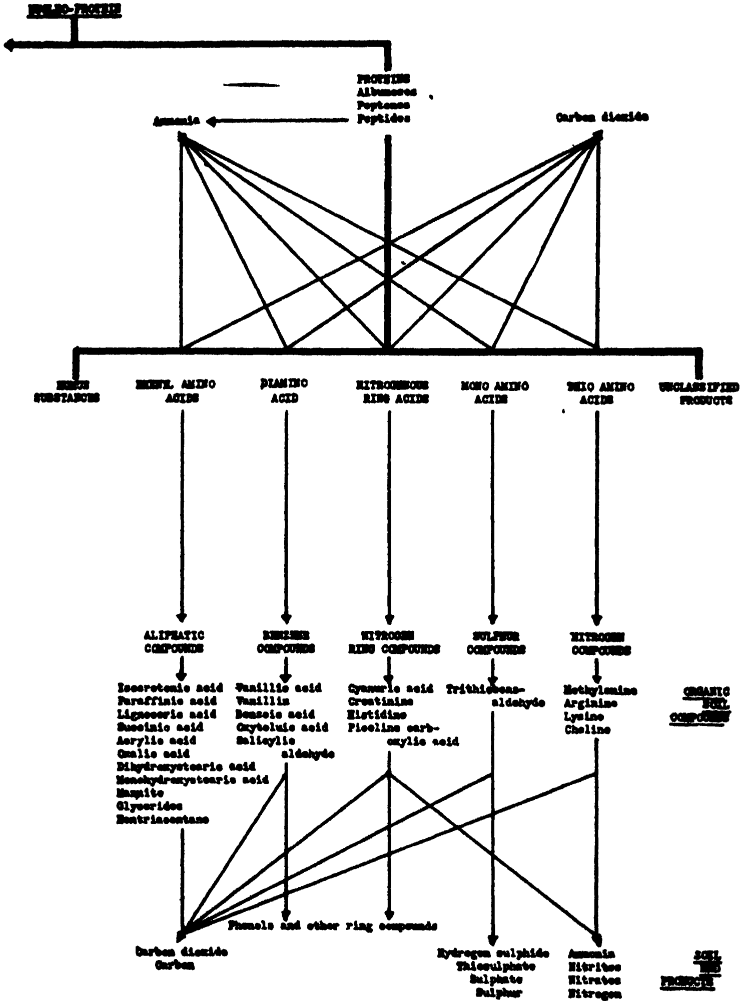


FIG. 1.—Diagrams illustrating the changes Changes taking place in a nucleo protein through the nucleic acid part of its structure, showing the production of many organic soil constituents, and end products.

The object in this work has been to determine definitely as many organic constituents of the soil as possible, and while this was tedious in the beginning as no methods of any kind existed for such work, the results have nevertheless been gratifying as the years have passed and sufficient compounds have been isolated to obtain a fairly good idea of the chemistry of the organic matter of soils and of the bio-chemical changes taking place therein. As you already know, some of these soil constituents contribute directly and indirectly to its fertility and some others, directly and indirectly, are factors in reducing the productivity of soils.

Both beneficial and harmful substances may be present in a soil simultaneously. Its productivity depends upon the balance of these two opposing factors; when one is decreased the other gains the ascendency. Any change in the soil may bring about a change in this balance of the opposing forces so that the soil becomes temporarily or permanently more fertile or less fertile as the case may be. Cultural methods, continuous cropping or crop rotation, green manuring,



taking place in the organic matter of soils.

Changes taking place in a nucleo protein through the protein part of its structure and of proteins generally, showing the production of numerous soil constituents, humus substances, and final products.

liming, or other processes resulting from human occupation can in the same way influence the biochemical factors in soils and through them affect this balance of good and harmful properties.

Now some of these organic soil compounds which we have isolated are found among the unit parts of which the complex constituents of every life cell are built; that is, they are the units obtained when one of the complex proteins, nucleo-proteins, etc., is resolved into simpler compounds by chemical means. Some other of these soil compounds are derived by further decomposition; by deamidization, oxidation, and reduction from these amino acids, carbohydrates, and other organic compounds, with liberation of ammonia, carbon dioxide, sulfuretted hydrogen, and other final as well as intermediate soil products. The accompanying diagram will make some of these exceedingly complex and involved chemical processes as clear as it is possible to do this in a non-technical manner. There is taken as an illustration a nucleo-protein. This complex can be split into a protein and a nucleic acid, both of which have been found in soils. The protein can be further split into a number of smaller units which are known as splitting products of protein or primary degradation products. These units or bricks out of which the complex structure of the protein is built comprise such compounds as histidine, arginine, lysine, and others. Those mentioned have all been found in soils and their beneficial action on plants demonstrated, but there are many others the action of which has not been determined nor has their presence in soils been established, possibly due to their greater susceptibility to change into other compounds, perhaps into those dark-colored substances of unknown constitution classed as humus bodies.

This process of taking the complex molecules apart into these units is accomplished by fairly simple means, involving chiefly the process known as hydrolysis; but to effect further decomposition of these units means more deep-seated changes and actual breaking up of the bricks themselves as it were. The diagram shows how by oxidation or reduction many of the soil compounds can arise during this process of change, and how finally the end products, ammonia, carbon dioxide, sulfuretted hydrogen, etc., are reached. In the soils, as is well known, the ammonia is again changed to nitrite and nitrate and thus, according to most authorities, the cycle is completed and the nitrogen is ready to start again on its mission to promote plant growth.

The building down of the nucleic acid which was one of the component parts of the nucleo-protein used in the illustration can be similarly traced. Like the protein part, nucleic acid yields smaller parts or bricks. The unit bricks of the structure of nucleic acid comprise such compounds as hypoxanthine, xanthine, guanine, adenine, cystine, pentose sugars, phosphoric acid, and others. All those mentioned have been found in soils. Like the splitting products of the proteins these can and do suffer further decomposition in the soil in which the nitrogen appears first as ammonia, then nitrite and nitrate as before, but again these changes mean the breaking up of the unit bricks which composed the nucleic acid structure.

That nucleic acid and others of the protein degradation products can directly serve as plant food in building up plant tissue has been shown in some of our investigations, in fact, the action of some of these in promoting growth almost resembles in effect the growth-promoting influence of vitamines in animal nutrition. On the other hand, the toxic action of many of the secondary products of these decomposition changes on plant growth has likewise been demonstrated, such as the various acid constituents, salicylic aldehyde, vanillin, etc.

This chart serves to show how both beneficial and harmful soil compounds may arise in the course of the organic changes which take place in soil, and illustrates how under a given set of cultural conditions beneficial compounds may predominate and under other conditions harmful constituents accumulate.

In closing, I would state that this brief presentation has shown, (a) that by existing data derived from analytical chemical methods we cannot hope to obtain an answer as to deterioration of soil organic matter as the result of human occupation of the land; (b) that soil organic research is fundamental, throws light upon the changes that take place in soils, and prepares the way for a study of the humus question in our agricultural lands including those changes that take place as the result of human influence on the natural equilibrium established in a soil under its environment of climate, drainage, native vegetation, etc.; and (c) that organic matter in the soil is essential to soil fertility in its maintenance of productivity and that increase in the soil's organic matter can be and is being attained by the use of manure, crop residues, and green crops plowed under in practical agriculture, to the end that, with the use of fertilizers properly balanced as to plant food requirements of soils and crops, an increase in productivity of our farm lands is, when nationally considered, already in evidence. The tide has turned from methods leading to decrease in soil fertility to an intelligent use of those methods which upbuild the Nation's resources in productive land.

The constructive research work of agricultural chemists and agronomists during the last century and the teachings of our agricultural extension forces is showing itself, not only in maintenance but in actual increase of production of agricultural commodities per unit of land throughout the world.

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2B. THE DEVELOPMENT OF TOXIC CONDITIONS[1]

BURT L. HARTWELL[2]

In general, all substances which affect crop growth are beneficial at sufficiently low concentrations. As the concentration increases a more or less definite point is reached where the beneficial effects are overpowered by toxicity influences.

Certain neutral substances have a very limited beneficial effect and yet may reach quite high concentrations before they become deleterious. These cause the toxicity illustrated by "white alkali" soils. When such salts are soluble, and alkaline in reaction, toxicity develops at much lower concentrations as in "black alkali" soils.

The highly important plant-food nutrients may be present in toxic concentrations not only under natural conditions, but because of their application in amounts unsuited to subsequent weather conditions. In usually humid climates, such large applications of manures and fertilizers are made in an attempt to attain maximum rate of growth of market garden crops that concentrations of nitrates, for example, may become equivalent to an application of as much as a ton of nitrate of soda an acre, an amount which one would certainly hesitate to apply.

Very little has been written to indicate that toxicity due to superconcentrations of certain fertilizer ingredients is likely to occur in humid regions under practical conditions. It is, however, a subject which must receive attention in circumstances of high fertilization from the viewpoint of a market gardener who is attempting to substitute fertilizers for stable manure.

It is not our purpose, however, within this limited time to emphasize the toxicity which occurs only under rather special conditions, but to attempt a direction of the discussion to a quite general soil situation embodied in acid-soil conditions.

Valuable as are certain measurements of these conditions in helping agronomists to interpret the degree of mutual appropriateness of soil and crop, they must be accompanied by many additional kinds of tests before a satisfactory diagnosis can be made of critical situations.

Too much dependence is still placed only on the determinations of acidity, whether measured by the concentration of hydrogen ions in the soil solution, or in any other way. This measures directly only one factor involved in acid-soil conditions, and probably not even the most important one at that.

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[1] Paper read as a part of the symposium on "Soil Deterioration" at the meeting of the Society held in Chicago, Ill., November 16, 1925. Contribution 323 of the Rhode Island Agricultural Experiment Station, Kingston, R. I.

[2] Director and Agronomist.

It has been known for years that acid soils are highly responsive to acid phosphate, but we are only beginning to appreciate that this material not only supplied phosphorus as a nutrient but also as an antitoxin for metals which act as poisons in acid soils. After this valuable function is already performed, the degree of acidity is no less than before, hence the inadequacy of its determination.

As agronomists, we must appreciate the fact that acidity may or may not be accompanied by such metals as aluminum, for instance, in toxic or in non-toxic combinations.

Obviously, acidity as such can be neutralized by alkaline materials. Aluminum can be counteracted by non-alkaline materials. Or the toxicity of both, and of the other toxic substances, can be greatly reduced by the presence of appropriate absorptive materials.

From the standpoint of the soil itself, measurements are needed not only of its alkaline absorptive properties as measured for instance by calcium oxid, but also of its acid absorption properties as measured by some acidic oxid of similar avidity to calcium oxid, and which forms with alkaline materials combinations of similar solubilities as those formed with calcium oxid.

We are liable to forget that the soil solids are to a considerable extent mixtures of more or less inactive alkaline and of acidic compounds, which because of their insolubility and low avidity do not form combinations with each other, but are in readiness to enter into combination with the more active material which may be applied to the soil. A soil which has a high calcium oxid absorption may or may not have an equivalent phosphorus pentoxide absorption, for example, and it is important to know the situation.

Acidity determinations need also to be accompanied by determinations of such metals as are suspected to be in toxic concentrations. These concentrations may not prove toxic to plants if accompanied by appropriate amounts of such antidotal, even non-alkaline, materials as phosphorus, silicon, and organic matter. Hence the estimation of these materials in active combinations may be necessary.

One cannot expect to do an intelligent job in coping with acid-soil conditions without a knowledge of all the factors involved, not the least of these being the factors introduced by the particular crop or crops to be grown. Very real difficulties may arise in overcoming the deleterious soil factors without at the same time preventing the optimum effect of such beneficial substances as iron and manganese.

A more intelligent appreciation of this situation will, it is hoped, lead to the omission from our text books of such statements as "soils should be neutral or slightly alkaline."

Fortunately, some crops exhibit chlorosis when suffering from difficulties caused by faulty assimilation of iron and manganese, but we need not expect to be fortunate enough to observe such visible symptoms on every crop which is suffering from over-liming. Strangely enough, some of the field crops which are most highly responsive to liming, spinach for example, are most seriously affected by chlorosis due to manganese deficiency. Incidentally, the actual observance of such deficiency in the field to such an extent that only three-fourths of a crop of spinach was obtained is of interest. When the same soil type had received less lime there was satisfactory growth and no manganese deficiency. It is frequently better practice, therefore, to maintain some acidity even with high-lime response crops, and to complete by liberal applications of a soluble phosphate the counteracting of such metal poisons as aluminum. When an application of a few pounds of manganese per acre means the success instead of the failure of a spinach crop, it is evident that it takes but a very small change to bring results in critical situations.

Even with what is considered ample fertilization, the differences in pronounced acid-soil conditions caused by the growth and removal of different crops alter the soil sufficiently to make remarkable changes in the growth of a subsequent crop which happens to be sensitive in such circumstances.

We need to know the calcium-oxid equivalent of that which different crops remove per acre of such acid soil. Some crops will doubtless be alkaline and others acid, and even if the differences are not great, it must be appreciated that the most active part of the soil has undergone some change and that at a critical point great alterations are not needed in order to affect crops.

Solution cultures are frequently useful in gaining indications of the comparative behavior of different species, but the mistake should not be made that even the soil solution represents quantitatively that which affects a plant growing in the soil. The activities at the contact surfaces of root hairs and near-soluble soil compounds are much more pronounced than between root hairs and the soil solution, whether nutrient absorption or toxicity is considered.

Even when soil measurements have been made of the different factors concerned in toxicity, the results will be useful to agronomists only when interpreted in terms of the growth of the different crops.

Standardization is needed of what shall constitute at least the medium magnitude of each kind of determination. We can then speak a common language and place ourselves in a better position for assigning the different crops to their appropriate niches. What are low, medium, and high degrees of acid-soil conditions? Why do not agronomists arrange collectively to have some of these limits defined?

The breadth of information required for a satisfactory solution of the problems under consideration need not disturb agronomists, because present recommendations leave such ample opportunity for improvement if greater use were but made of the light which is already available.

2C. REMOVAL OF PLANT NUTRIENTS IN DRAINAGE WATERS[1]

J. A. Bizzell[2]

The removal of certain of the plant nutrients from the soil by drainage waters is of considerable economic importance. A large amount of information bearing on this subject has been published, but unfortunately a strict interpretation of the reported data does not lead to many definite conclusions. Satisfactory equipment for the quantitative determination of losses in drainage and the analytical work involved are expensive. The result has been that the number of strict and conclusive comparisons under a given set of soil and climatic conditions has been small. Again, there is some reasonable doubt as to the adequacy of the methods employed.

Two general methods have been followed. The first consists of the chemical analysis of waters from rivers, small streams, and tile drains. Since there seems to be no satisfactory way of measuring the total amount of drainage water, this method does not show us the total losses of plant nutrients by leaching. Reported data also indicate that generally river water contains much less soluble matter than does water issuing from tile drains or from drain guages.

In the second method use is made of lysimeters or drain guages—water tight vessels, containing soil so arranged that the water percolating through the soil can be collected, measured, and analyzed.

The drain guages at Rothamsted, England, and Aberdeen, Scotland, were built around a block of soil *in situ*. In other cases the lysimeters appear to have been filled after the soil was thoroughly mixed. It has been shown that the thorough breaking up and aeration which the soil undergoes in this case profoundly affects the amount and composition of the drainage so that considerable time is required for the soil to settle down again to its natural condition. A lack of recognition of this and other vital facts has led the writer to believe that much of the data obtained in percolation experiments are of questionable, though, in many cases, of corroborative value. The limitations of this paper do not permit a critical discussion of methods. Brief reference is here made to the question of methods because of its bearing on the writer's interpretation of drainage water analyses.

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[1] Paper read by title as a part of the symposium on "Soil Deterioration" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] Professor of Soil Technology, Cornell University, Ithaca, N. Y.

REMOVAL OF CALCIUM

Analyses of drainage water practically all agree in one respect, *viz.*, that calcium is the predominant constituent In fact, with few exceptions, the amount of calcium in any particular case has been equal to, if not greater than, the sum of the amounts of the other nutrient constituents Reports show that the quantities of calcium removed in the drainage water vary over a wide range This variation is obviously due to differences of soil, treatment, cropping, and climate When we attempt to segregate and evaluate the factors involved we find that the evidence is rather meager

It seems to have been satisfactorily demonstrated that in general cropping *decreases* the removal of calcium by drainage water Thus, Lyon and Bizzell (9, 10)[3] have shown that the average annual losses per acre of calcium expressed as CaO from two soils, a silt loam and a clay loam, during a period of five years, were for the cropped soils 311 pounds and for the uncropped soils 503 pounds These findings have been corroborated by results reported elsewhere. The relative effect of different crops on the removal of calcium has received little attention. Reported results are too inconclusive to warrant discussion in this paper.

Fertilizer treatment has been shown to have pronounced effects on the amount of calcium appearing in drainage waters. It seems desirable to describe briefly some recent experiments on this subject. Hall and Miller (6) found that the lime content of water from the tile drains underneath the fertilizer plats of Broadbalk field, Rothamsted, was influenced mainly by the character of the nitrogenous fertilizers. Drainage water from the unmanured plats contained 99 ppm. of lime, while that from the plat treated with ammonium salts contained 196 ppm. of lime. The figures for the sodium nitrate were intermediate between these two, being 126 ppm. The total disappearance of calcium from these soils was estimated by determining the residual calcium carbonate after a period of 40 years. The average annual losses per acre of calcium carbonate were from the unmanured plats 800 pounds; from the plat receiving ammonium salts, 1,100 pounds; and from the plat receiving sodium nitrate, 565 pounds.

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[3] Reference by number is to "Literature Cited," p. 136.

Morse (13) reported some interesting data showing the effect of nitrogenous fertilizers on removal of calcium. The general plan of the work seems to have been identical with that followed by Hall and Miller (6). Analyses were made of the water from tiles underneath field soils treated with fertilizers. Observations extending over a period of nine years showed the following amounts of calcium in the drainage water: From the unmanured soil, 36.5 ppm.; from the soil treated with ammonium sulfate, 54.2 ppm.; and from the soil treated with sodium nitrate, 24.8 ppm. Determinations of the residual calcium carbonate after a period of nine years showed that the untreated plat contained 1,183 pounds $CaCO_3$, while the plat treated with ammonium sulfate contained 777 pounds $CaCO_3$ and the plat treated with sodium nitrate contained 1,585 pounds. These figures were calculated on the basis of the acre 6 inches.

The comparatively short-time percolation experiments by Hendrick (8) and by Eckart (3) seem to substantiate the findings of Hall and Miller and of Morse. None of these experiments is entirely satisfactory from a quantitative point of view, yet the results obtained by different methods point to the same conclusion, *viz.*, that ammonium sulfate added to the soil markedly increases the amount of calcium appearing in the drainage water.

Regarding the effects of applications of lime, potassium salts, and phosphates on the removal of calcium in drainage water the reported data do not appear to be sufficiently extensive and conclusive.

REMOVAL OF MAGNESIUM AND POTASSIUM

The magnesium content of drainage water has been determined in a number of cases, but does not appear to give us information of much economic importance. A similar statement may be made concerning potassium, although the latter has received a somewhat greater share of attention from investigators.

REMOVAL OF NITROGEN

Analyses show that the nitrogen of drainage waters is almost entirely in the form of nitrates. A few cases have been reported in which organic nitrogen and ammonia were present, but always in small and practically negligible amounts. Generally, the effect of cropping is to reduce, and in some cases to prevent almost entirely, the presence of nitrates in the drainage. Crops appear to differ widely in this respect. Although several interesting observations have been made, the subject has not received the attention that its importance would seem to justify.

Deherain (2) observed that the amount of nitrates in the drainage from cropped soil depended upon the kind of plant grown. From soil in pots cropped to oats and rye grass 26 mg. of nitrate nitrogen were leached, while from soil growing peas and clover under similar conditions 200 mg. nitrate nitrogen were removed.

The results of Hanamann (7) showed that the drainage from soil growing clover contained more nitrogen than did drainage from soils growing barley, sugar beets, corn, or horse beans. Welbel (17) found more nitrates in drainage from soil growing alfalfa than from one growing wheat.

Drainage investigations at the Geneva (N. Y.) Experiment Station reported by Thatcher (16) have shown that the lysimeter tanks containing a soil under a four-year rotation including two years of alfalfa lost over seven times as much nitrate nitrogen as did the same soil under a rotation in which two years of timothy replaced alfalfa. It is interesting to note that the barley crop following alfalfa was 4,370 pounds per acre larger than where barley followed timothy. From these and other investigations it would appear that soils growing legumes are more likely to be deprived of their nitrogen by leaching than are the same soils growing grasses and similar crops. This tentative conclusion is substantiated by numerous reported data showing that some legumes, at least, favor the production of nitrate nitrogen in the soil.

From reported data it appears that losses of nitrogen in drainage waters are influenced very largely by the application of nitrogenous fertilizers to the soil. Strictly speaking, perhaps, this is not a case of soil deterioration, but since it is an important problem involving nitrogen economy it seems desirable to discuss briefly the available evidence. Eckart (3) applied ammonium sulfate and nitrate of soda separately to soils in lysimeters and determined the amounts of nitrogen appearing in the drainage after eight months. The soils treated with ammonium sulfate yielded 75.58% of the nitrogen applied, while soil treated with sodium nitrate gave a recovery of 90.2%. Collison (1) determined the drainage losses from a coarse sandy soil to which moderate amounts of nitrogenous fertilizers had been applied. The recovery calculated as percentages of applied nitrogen was as follows: From the sodium nitrate treatment, 72.5%; from ammonium sulfate, 41.0%; and from dried blood, 38.3%. One orange tree was growing on each lysimeter during the observations.

The comparative effects of ammonium sulfate and nitrate of soda on two types of soil, a sand and a loam, were studied in lysimeters by Geilman (4). The soils were treated with large quantities of nitrogen and were kept bare during the observations. The sodium nitrate produced a puddled condition in the loam soil and the effect persisted for two years. The ammonium sulfate produced no similar effect. The loam soil treated with sodium nitrate yielded 97.4 liters of drainage water, while the same soil treated with ammonium sulfate gave 136.8 liters. During two years the removal of nitrogen from the loam soil calculated as percentage of applied nitrogen was as follows: From the sodium nitrate treatment 13.5 and from the ammonium sulfate treatment 20.5. The sandy soil gave entirely different results. From the latter 75% of the nitrogen from the sodium nitrate treatment was removed in about five months, while the nitrogen recovery for the ammonium sulfate treatment for the same period was 16.6%. At the end of two years the sodium nitrate treatment showed a total of 103.59% nitrogen recovery, while the figures for the ammonium sulfate treatment were 77.9%. Hendrick (8) reported percolation experiments in which large amounts of ammonium sulfate were applied to the soil, but the results do not contribute to the present discussion. The work of Eckart, Collison, Geilman, Hendrick, and others give us little information of practical significance. It is frequently stated that the nitrogen of applied sodium nitrate is quickly leached from the soil and that the nitrogen of ammonium compounds is not so susceptible of loss. This broad generalization has not yet been demonstrated by suitable experimentation.

In connection with the nitrogen losses in drainage the work of Russell and Richards (14) is very interesting. The unmanured and uncropped drain guages at Rothamsted are so well known that description is unnecessary. The nitrogen losses from the soil in these drain guages have been carefully determined over a long period of time. At the beginning, in 1870, the soil contained 3,500 pounds nitrogen per acre in the top 9 inches and it then gave up 40 pounds of nitrogen per acre annually to the drainage water. At the end of 50 years the soil contained 2,381 pounds of nitrogen per acre in the top 9 inches and gave up 21 pounds of nitrogen per acre annually to the drainage water. Analysis of the soil showed that practically all the nitrogen lost from the top 9 inches could be accounted for by the nitric nitrogen in the drainage. There appears to be no room for the assumption of nitrogen fixation nor nitrogen evolution unless these two factors were equal.

REMOVAL OF SULFUR

There is not a great amount of published data concerning the removal of sulfur by drainage water. Experiments by Hanamann (7), Von Seelhorst and Fresenius (15), Gerlach (5), Lyon and Bizzell (9), and others have shown that in general cropping decreases the removal of sulfur by leaching. The experiments by MacIntire, Shaw, and Young (11, 12) indicate that applications of certain calcium or magnesium compounds are followed by an increase of sulfur appearing in the drainage With untreated soil the amount of sulfur in the drainage was less than that brought down in the rain, while with the treated soils the drainage contained more sulfur than did the rain water. Correlation of comparable rainfall and drainage statistics are not sufficiently extensive to indicate whether rainfall can be expected to supply enough sulfur to compensate for the drainage losses and the sulfur needed for crops

REMOVAL OF PHOSPHORUS

Of the rather large number of drainage water analyses none have ever shown more than a very small phosphorus content Considering the wide range of variations in treatment and in climatic and soil factors obtaining in the experiments reviewed, there seems to be no danger of the depletion of soil phosphorus by leaching

CONCLUSIONS

1. Large quantities of calcium are removed from soil by drainage waters. Calcium is the predominant constituent generally amounting to more than all other nutrients together The effect of cropping is to decrease the amount leached· Application of ammonium salts, especially ammonium sulfate, markedly increases the loss of calcium.

2. The quantities of magnesium and potassium removed by drainage water are appreciable but not excessive The factors affecting this removal are not known.

3. Nitrogen appears in drainage waters almost entirely as nitrates. The general effect of cropping is to reduce the amount lost. There appears, however, to be a more specific effect. The loss from soil growing legumes appears to be greater than from soil growing nonlegumes. The comparative effect of nitrogenous fertilizers on the removal of nitrogen has not been satisfactorily determined.

4. The amount of sulfur removed by drainage is comparatively large, but there is yet insufficient evidence to show whether this loss has an economic significance.

5. The removal of phosphorus by drainage is practically negligible.

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2D. THE MICRO-BIOLOGICAL COMPLEXES OF THE SOIL AND SOIL DETERIORATION[1]

SELMAN A. WAKSMAN[2]

To be able to understand the various chemical processes which take place in the soil and which lead to fertility or unfertility, it is essential to know the origin and nature of the soil organic matter and the nature and activities of the micro-organisms inhabiting the soil. It is also essential to understand the chemical processes brought about by these organisms and the various antagonistic and associative influences governing these processes.

All life phenomena involve the transformation of energy. All substances, of organic or inorganic origin, which represent sources of energy will be acted upon, sooner or later, in one way or another, by one or more groups of soil micro-organisms Some of these energy sources, like the various carbohydrates or proteins of plant and animal origin added to the soil, can serve as sources of energy for different groups of micro-organisms; other sources of energy, especially various inorganic substances (sulfur, ammonium salts) and certain organic substances (as lignins), can be utilized only by certain limited specific groups of micro-organisms.

In the process of decomposition of the organic substances or oxidation of the inorganic sources of energy, a part of the energy made available is utilized by the micro-organisms concerned in the processes for the synthesis of microbial protoplasm. The quantity of protoplasm synthesized depends upon the nature of the nutrients, nature of organisms, and the environmental conditions This synthesized protoplasm contains a definite amount of nitrogen, phosphorus, and potassium, in addition to other minerals which are consumed in smaller amounts. These elements are obtained by the micro-organisms either from the materials added to the soil or from those already present in the soil. Since these elements are also essential for the growth of the higher cultivated plants, competition between these and the micro-organisms may take place. This depends entirely upon the balance between the amount of energy made available for the latter and the minerals required for their synthetic activities. A clear understanding of these processes, as well as of the chemistry of the organic materials constantly added to the soil and of their decomposition by micro-organisms, will help us to obtain a proper insight into soil fertility and soil deterioration.

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When natural organic matter is added to the soil or when it is made available by the plowing under of sod or plant stubble, a great many micro-biological activities immediately set in. The extent and continuation of these activities depend on the amount and the nature of the materials which can be used as sources of energy by the soil population. The more important plant constituents comprise (1) substances immediately or readily made available to the micro-organisms as sources of energy. Here belong the monosaccharides, starches, pentosans, pectins, celluloses, and proteins and their derivatives in approximate order of rapidity of decomposition. Certain inorganic sources of energy, which may be added to the soil but which are largely formed as a result of the decomposition of the organic materials under specific conditions, could also be mentioned here, such as ammonium salts, sulfur, hydrogen, and methane. (2) Substances not very readily acted upon by micro-organisms and which may, therefore, even though representing potential sources of energy, persist in the soil for a considerable period of time without being decomposed. Here belong various plant constituents, namely, the lignins, fats, and waxes, and certain components of the cells of micro-organisms. These have been synthesized in the process of utilization of the first group of substances as sources of energy. The exact chemical nature of most of these is very little known at the present time.

The soil micro-organisms can also be divided into two groups. (1) Those which become active only when fresh sources of energy are added to the soil, especially the constituents of the first group of energy materials. Here belong the soil fungi and numerous groups of bacteria followed by the protozoa. These organisms make an abundant growth and, in the presence of sufficient available nitrogen and minerals and favorable environmental conditions, rapidly use up the available energy sources. A part of the carbon, usually more than 50%, is liberated in the form of CO_2 into the atmosphere. A part, often only a very small part, is left in the form of various intermediary products. Another part of the carbon, often as much as 30 to 40% of the original, is stored away in the form of microbial protoplasm or as newly synthesized substances. Some of the intermediary and synthesized products can serve as sources of energy for other organisms, perhaps, under favorable conditions, even for nitrogen-fixing bacteria. In the anaerobic decomposition of energy sources a somewhat different relationship is found to hold true. (2) The second group contains those micro-organisms which grow only very slowly and are found to be always active in the soil upon the colloidal film covering the inorganic soil particles. These organisms are capable of attacking the more resistant substances comprising the second group of energy sources. Here belong various non-spore-forming bacteria and actinomycetes.

The biological processes in the soil leading to the liberation of the elements which represent the nutrients required by higher plants, namely, nitrogen, phosphorus, and potassium, are very complex. They can be presented here only schematically as follows.

A sod soil contains the largest part of the nutritive elements (N, P, K, S) in its organic constituents. Only traces of nitrogen can ever be present in the soil in the form of ammonia or nitrate, the former being rapidly transformed, in the presence of sufficient lime or other buffering substances, into nitrates. This is either reassimilated by the growing roots or by the micro-organisms which are thus enabled to attack the available energy supply. The same is true, to a somewhat lesser extent, of the phosphorus and potassium, although the former may form insoluble compounds with the soil bases and the latter may be absorbed to a limited extent by the soil zeolites, with a replacement of bases. The same is true of the sulfur. Any excess of nitrates or sulfates would probably be washed out, although this is hardly possible in a sod soil. The calcium is found in the great majority of soils as the base saturating the soil zeolites.

When this sod soil is plowed under, the large quantity of undecomposed plant residues, stems, leaves, and roots are immediately attacked by the soil fungi and bacteria, which utilize the energy thus made readily available. The first organic constituents to disappear are the carbohydrates and, in general, those substances which were included above in the first group of energy materials. The decomposition of these will result in the synthesis of a proportional amount of microbial protoplasm. The nitrogen and minerals made available in the decomposition of the plant residues may largely again be stored away by the micro-organisms and only a small part may be made available to the growing plant. This is very fortunate from the economic point of view, otherwise the rapidity with which the organic matter is decomposed would result in the liberation of nutritive substances which would be largely wasted away, either into the atmosphere or in drainage waters.

When the soil is plowed the second season, very little of the original available constituents of the sod may be left. The organic matter is now made up (1) of a small amount of the available sod constituents still undecomposed, (2) a smaller or larger amount of available constituents of the plant stubble plowed under with the first year's crop, (3) a large quantity of the sod constituents which have resisted decomposition, and (4) a large quantity of synthesized microbial substances. These processes resulted in a narrowing of the carbon-nitrogen ratio of the organic matter added to the soil, tending from an original 80 40 to 1 in the native plants and roots to 10 to 1 in the soil organic matter itself. The nature of the action of the micro-organisms is now somewhat different. The same active groups will attack the readily available energy left from the sod and introduced by the fresh plant residues as well as the available constituents of the cells of micro-organisms. The slow growing organisms are now largely at work, slowly attacking the resistant constituents of the plant materials and of the synthesized microbial cells, both of which go to make up the resistant soil "humus." The amount of nutritive elements now made available will depend upon the conditions favoring the activities of the latter group of organisms. It is sufficient to mention that liming of the soil, proper aeration, and a proper temperature are among the most important factors favoring the activities of these organisms and, therefore, the decomposition of the soil organic matter or of the soil "humus." If there is still an excess of available energy, no nitrogen and minerals will be liberated from the decomposition of the organic matter. Nevertheless, as soon as the available energy is reduced to a minimum, the further decomposition of the organic matter, however slow, results in a constant and gradual liberation in an available form of the nitrogen and minerals stored away in the soil organic matter.

The fertility of a soil or the amount of nutritive elements that can be made available in a given soil, under favorable treatment and under a given set of environmental conditions, can thus be considered to be a balance between the nutritive elements added anew to the soil, in the form of fresh plant stubble, green manures, stable manures, and organic fertilizers, on the one hand, and the slow but gradual break up of the resistant part of the soil organic matter ("humus") on the other. The first tend to increase the amount of soil organic matter and, therefore, of the potential plant nutrients stored away in the soil. In the presence of an excess of available nitrogen and minerals or when a sufficient time has elapsed after the addition of the fresh organic matter, the nutrients will be also immediately available for plant growth. The second tend to reduce the amount of energy stored away in the soil and liberate the locked up nutrients in an available form. However, the non-nitrogenous nutritive elements for plant growth may exist in the soil in inorganic combinations and as such may not become controlling elements in soil deterioration as the nitrogen and that part of the minerals which are present in the soil in the organic complexes.

In general it may be said that soil deterioration from the point of view of the practical farmer is something different from that considered by the soil biochemist. The former is interested in the quantity of nutrients that becomes available in a given season. He may add the necessary nutrients in the form of artificial fertilizers and obtain perfect results. The microbiologist is interested in the reduction of the energy stored away in the soil in the organic complexes which leads to the liberation of the nutrients locked up in these. This reduction of energy accompanied by the liberation of the nutrients finally leads to soil deterioration, unless the supply of this energy is kept up. However, the earlier theories which suggested a rapid exhaustion of soil, due to the depletion of the soil "humus" or mineral elements, have not considered the nature of the soil organic matter and the rôle of micro-organisms in its decomposition. When these factors are considered sufficiently, no immediate danger need be experienced. This organic matter once formed is not readily broken up again.

The fertility of the soil at a given moment thus depends upon the balance between the building up and the breaking down of the soil organic matter, on the one hand, and the balance between available nutrients added to the soil (both from outside and made available through the activities of micro-organisms) and removed from the soil, on the other. While the growth and activities of micro-organisms in the soil depend largely upon the first balance, the growth of higher cultivated plants depends upon the second balance which is supplemented by the results of the activities of the micro-organisms.

From this point of view, artificial fertilizers alone will never increase the fertility of a soil unless properly balanced with crops which would allow the introduction of sufficient organic matter into the soil so as to compensate the loss of the soil organic matter.

The rôle of micro-organisms in the various transformations which take place in the soil and which result in the liberation of nutrients for higher plants thus consists in (1) the breaking up of a large part of the original organic matter added to the soil which results in the liberation of most of the nitrogen and minerals. Fungi and various groups of bacteria are largely concerned in this process. (2) It comprises the reassimilation of a larger or smaller part of these nutrients and the building up again into microbial protoplasm which goes to form a part of the soil organic matter. The balance between the amount of nutrients reassimilated by the micro-organisms and the amount left for the use of higher plants depends upon the concentration of these nutrients and the amount of available energy introduced into the soil. Algae, fungi, bacteria, protozoa, and other invertebrate animals are largely concerned in this process. (3) It includes the transformation of the nutrients, liberated in the first process and not reassimilated by the micro-organisms, into forms available for higher plants (ammonia changed to nitrates, hydrogen sulfide to sulfates, etc.). Bacteria are largely concerned in these processes. (4) It includes the slow and gradual decomposition of the soil "humus," under favorable conditions of reaction, aeration, etc. Actinomycetes and certain non-spore-forming bacteria are largely concerned in this process.

Soil exhaustion, from the point of view of micro-biological complexes, can be as accurately calculated as a mathematical equation when all the factors are considered. It is an equation with too many unknowns and, even more unfortunately, with too many variables. However, the working out of such an equation is not beyond the present meager stage of our knowledge of the subject.

An attempt was made only a few years ago to explain soil exhaustion, at least in the case of certain soils, as due to the predominance of certain organisms which may feed upon the beneficial soil bacteria. The destruction of those organisms by partial sterilization of the soil was thought to be the explanation for the beneficial effects of this treatment. However, this theory as well as other theories based either upon the competition between different groups of organisms for the available nutrients in the soil or upon the equilibrium that may become established between different groups of soil organisms can only tend to throw further light upon the complex problem without explaining it fully.

Also, no allowance has been made in the above system for possible infertility which may result from a change in the soil reaction which may lead to unfavorable conditions for the growth of plants or micro-organisms; also for infertility which may be due to the lack of one or more mineral elements in the soil, or for seeming infertility which may be due to the accumulation of general or specific parasites.

2Ea. THE ROLE OF INSECTS IN SOIL DETERIORATION[1]

J. W. McColloch[2]

Since insects constitute one of the largest groups of the soil fauna, they are an important factor in the soil environment. It has been stated that 95% of all insect species invade the soil at some period in their life From surveys which have been made in many localities, it is known that every acre of arable farm land harbors millions of insects. Occurring in such enormous numbers, it is evident that they must be an important factor in many soil problems.

There has been a tendency to consider soil-inhabiting insects as beneficial, since they are important agencies in promoting soil formation, renovation, and maintenance. In a previous paper (9)[3] an attempt was made to show that there is a reciprocal relation between the soil and its insect population. Insects utilize the soil for shelter, protection, materials of abode, food, moisture, air, heat, and as an avenue of travel. In return, the soil is benefitted through the interchange of soil, separation of soil particles, aeration, drainage, and the addition of organic matter.

The part which insects play in soil deterioration has been given very little consideration. It presents an excellent problem for cooperative work between the soil technologist and the entomologist. The economic importance of the relationship between soil-inhabiting insects and the physical, chemical, and biological conditions of the soil is far reaching in its application. Economic entomologists, and particularly those engaged in the study of the cereal crop insects, have found that a study of the soil is fundamental to the development of many control measures. Undoubtedly the agronomist likewise will find that a study of soil-inhabiting insects is necessary in formulating recommendations for cultural measures, crop rotations, and soil treatments. The agronomist is concerned primarily in the development of the best agronomic practices in order to secure the highest possible yields. Unknowingly he may be recommending certain measures conducive to the favorable development of some soil-inhabiting insect. Thus, soil entomology becomes an important factor in many agricultural problems just as soil technology is fundamental to insect control.

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[1] Paper read by title as a part of the symposium on "Soil Deterioration" at the meeting of the Society held in Chicago, Ill., November 16, 1925. Contribution No. 350 from the Entomological Laboratory, Kansas State Agricultural College, Manhattan, Kansas. This paper embodies some of the results obtained in the prosecution of Project 100 of the Agricultural Experiment Station.

[2] Professor of Entomology.

[3] Reference by number is to "Literature Cited," p. 149.

Time does not permit of an extended discussion of the rôle insects play in soil deterioration or for a comprehensive review of the literature Frequently the detrimental effects are obscured by other agencies. In many cases they are indirectly associated with other factors, while in some instances soil deterioration is the direct result of insect activities. The present discussion, therefore, illustrates some of the important ways in which insects directly or indirectly influence soil deterioration and emphasizes the need of more careful consideration of soil-harbored insects in agronomic work.

LIMIT CROP PRODUCTION

Soil-inhabiting insects may be an important factor in soil deterioration in that they may limit crop production. Anderson (1) reports that the abundance of the slender wireworm on the light, sandy soils of certain areas in South Carolina made it necessary to abandon or "rest" the land. The distribution of this insect is closely related to light, sandy soils which do not retain moisture, and Thomas (14) states that land subject to infestation by this wireworm can be detected by walking over it.

It is a well-known fact that in many sections of the United States it is impossible to grow certain crops because of white grub attacks. One of the most difficult problems in many cities of Kansas is to maintain a bluegrass lawn or a strawberry bed due to the prevalence of these grubs

Soils rich in humus or organic matter are attractive to a number of insects. The green June beetle, root maggots, and wireworms are frequently mentioned in literature as being particularly abundant in such soils. Low, heavy, poorly drained areas harbor several species of wireworms injurious to corn. In some regions corn cannot be produced on such land because of these pests until drainage is provided. Phillips and Fox (13) state that the favorite breeding place of the rough-headed corn-stalk beetle is low, poorly drained land that has been allowed to remain as waste or pasture for considerable periods of time.

In this connection it might be mentioned that insects prohibit the continuous growing of the same crop on the land. Osborn (12) emphasizes this point in the case of land that has been under cultivation and then allowed to remain as pasture or meadow. At some point, usually in about three or five years, there is a striking drop in productivity The pasture is said to have "run out" or suffered "soil exhaustion." In reality, the land has become occupied by such a dense population of insects as to inhibit plant growth. The growing of corn for a period of three or more years in the same fields often results in severe infestations of the corn root worms and the corn root aphis. The wheat white grub is a limiting factor in continuous wheat production on many farms in Oklahoma and southern Kansas. The females of this species are wingless and, consequently, on maturing, remain in the same field. Thus the infestation increases rapidly with each generation until it is necessary to change the land to a row crop for a year.

INFLUENCE ON CROP ROTATIONS

The influence of soil-harbored insects must be considered in planning a crop rotation. The rotation of crops is one of the more generally recommended measures for crop improvement. It is also advocated in many cases as a good practice for insect control. Very frequently, however, in the recommendations for crop sequences, the insect factor is not recognized, and thus favorable conditions are provided for the development of certain insect pests. In changing from a grass crop to a grain crop, i. e., from sod to corn, it is generally recognized that there is danger of injury by white grubs, wireworms, cutworms, and sod webworms. In such rotations, an interval of time should elapse between the destruction of the old crop and the planting of the new one. Forbes (4) has shown that May beetles prefer to oviposit in grass land and that white grub injury may be expected the following year if this is plowed under and planted to some other crop.

In order to maintain a continuous pasture in some dairy sections of Kansas, it is a common practice to grow Sudan grass during the summer and follow this with rye in the fall. Several such fields were under observation in 1924, and it was found that the adults of the spotted cucumber beetle (*Diabrotica 12-punctata*) and of one of the smaller click beetles (*Drasterius elegans*) were attracted to the Sudan grass in large numbers for egg deposition When the Sudan grass was plowed under and the land sown to rye, the larvae of these insects attacked the roots of the young plants and destroyed the stand.

Numerous examples of the relation between insects and crop diversification might be cited. Every community has its particular problems relative to cropping systems and insect depredations. Hunter (6) gives a comprehensive survey of the relation between rotation systems and insect injury in the southern states. In general, however, it may be stated that this is an important field for cooperative investigation on the part of the agronomist and the entomologist. The failure of the economic entomologist to recognize the necessity of a fundamental study of the agronomic phases in his recommendations and of the agronomist to consider the part insects play has resulted in considerable confusion. As Fernald (3) points out, the entire subject of crop rotations which are satisfactory from the standpoint of agriculture and also correct when insect problems are considered is still in a far from settled condition, and needs prolonged investigation.

INFLUENCE ON NITROGEN FIXATION

The growing of cowpeas, soybeans, or some other legume is a common recommendation for soil improvement. Such crops add nitrogen to the soil through the nodules produced on their roots. Within recent years it has been found that a number of soil-inhabiting insects feed upon these nodules and in some cases are an important factor in limiting nitrogen fixation.

McConnell (10) found the larvae of the bean leaf beetle (*Cerotoma trifurcata*) feeding on the root nodules of cowpeas and soybeans in Mississippi. The larvae were most destructive on the poorer soils where soil enrichment through the growth of legumes was of great importance. In some cases, the larvae destroyed practically all of the nodules and also injured the roots.

Leonard and Turner (7) conducted a series of experiments on the relation of the larvae of the bean leaf beetle to nitrogen fixation. They state that since the nodules of leguminous plants are recognized as fundamental sources of nitrogen for plant growth, any agency which tends to impede their normal function or interfere with their nitrogen fixing function is worthy of scientific consideration. Their studies indicate that the nodule injury is related to the percentage of nitrogen in the roots. As the injury to the nodules increased, the percentage of nitrogen in the roots decreased and the nitrogen lost was in proportion to the numbers of larvae present.

Other insects have also been reported attacking the nodules on legumes. McConnell (11) records the larva of a snout beetle (*Eudiagogus rosenschoeldi*) feeding on the roots of *Sesbania macrocarpa*, and Leonard (8) found mealy bugs on soybeans and other legumes.

INFLUENCE ON CULTURAL PRACTICES

The influence of soil-inhabiting insects on the practice of certain cultural methods can be illustrated by several observations made by the writer in Kansas. While investigating an outbreak of the kafir ant in the sorghum fields of southern Kansas in 1911, it was noted that in every case the injury was more pronounced in surface-planted fields. Where the crop had been listed, very little damage occurred and subsequent studies have borne out these observations.

A similar case was encountered in the corn experiments on the experiment station farm at Manhattan. In 1924, experiments involving three methods of planting corn were conducted on land that proved to be heavily infested with wireworms. An examination of the plats planted April 11 showed that there was a marked difference in the wireworm damage with relation to the method of planting. Forty-five per cent of the hills in the surface-planted plat had been injured, the open furrow plat had 19% of the hills infested, while the listed corn showed an infestation of only 9%.

INFLUENCE ON THE USE OF FERTILIZERS

Barnyard manure is considered an excellent fertilizer and is used extensively in many areas for soil improvement. Many insects are attracted to land enriched with this material and in some cases it is necessary to change to the use of commercial fertilizers. *The green June beetle and the muck beetles prefer soils heavily fertilized with animal manures.* The application of barnyard manure to lawns in Kansas usually results in excessive damage by certain species of white grubs. Injury to corn, beans, and peas by the seed corn maggot is most frequent in fields where manure recently has been plowed under.

INFLUENCE OF INSECT CONTROL MEASURES

The control of injurious species of soil-inhabiting insects may have considerable influence on soil deterioration. Within recent years much experimental work has been done with various *soil insecticides and fumigants.* These are all chemicals which must undoubtedly affect the physical, chemical, and biological properties of the soil. Such materials as carbon disulphide, sodium cyanide, calcium cyanide, petroleum products, coal tar products, corrosive sublimate, paradichlorobenzene, potassium sulphocarbonate, and many others have been recommended for this purpose. The experimental work for the most part has been along two lines: First, to determine the minimum dosage necessary to control the insect, and, second, the maximum dosage that can be applied without injury to the vegetation. *Very little attention has been given to the effect of these chemicals on the soil, and there are many questions which must be answered before such materials can be recommanded for general use.* What changes take place in the structure, texture, and organic matter of the soil? How do these chemicals affect the micro-organisms such as the protozoa and the nitrifying bacteria? Is there an accumulative effect through repeated applications? A summary of the experimental work indicates that no satisfactory insecticide has been found which can be depended upon under the varying conditions existing in the soil. The problems connected with the use of soil insecticides must be along three general lines: (a) The development of an insecticide that is effective against the insect and at the same time not injurious to vegetation, (b) the influence of soil conditions on the effect of the insecticide against the insect and on the vegetation, and (c) the effect of the insecticide on the various properties of the soil.

MECHANICAL INJURY

The presence of burrowing insects in the ground is usually considered beneficial since they cause the movement of the soil along more or less definite lines and produce an interchange of the subsoil with the upper layers. The ground is also opened up for better aeration and drainage. The value of these benefits is sometimes offset by certain injuries resulting from abnormally large numbers of insects in the ground and the continual agitation of the soil. The tunnelling of ants and certain white grubs in lawns, turfs, meadows, pastures, and golf greens frequently renders the soil soft and spongy. *Such excessive working of the ground keeps the soil pulverized, with the result that the roots of plants do not maintain their hold and the crops die.* Davis and Lugirbill (2), writing of the activities of the green June beetle grubs, state that the ground may become so porous that evaporation increases and the plants therefore suffer from lack of moisture.

The bringing of large quantities of dirt to the surface by many insects is often detrimental in that the dirt covers the vegetation and, on being trampled, smothers the plants. One of the important problems in connection with the upkeep of golf greens in the southeastern states is due to the soil brought to the surface by the grubs of the green June beetle. The mounds of earth thrown up by this insect mar the appearance of the course, kill the grass in spots, and produce an irregular surface which prevents accurate putting.

Another type of injury which might be mentioned under this heading is the result of those insects which burrow to some depth in the ground. This results in a more porous subsoil and, during rains, much of the soluble soil nutrients in the surface layer may be carried down where it is not readily available to the plants.

CONCLUSIONS

Soil-harbored insects play an important rôle in soil deterioration. Directly or indirectly, they may limit crop production, influence crop rotations, nitrogen fixation, cultural measures, and the use of fertilizers. Their burrowing activities may cause certain mechanical injuries, and finally the application of soil insecticides for the control of subterranean pests may have a deleterious effect on the physical, chemical, and biological properties of the soil.

The agronomist cannot afford to neglect the insect factor in experimental work involving cultural practices and cropping systems. Differences in yields in various types of plat work may be due to insect activities rather than to the plat treatment. The fact that May beetles prefer grassland for oviposition would be an important factor in a series of rotation plats since crops following grass would be subject to white grub injury the next year. The preference of certain insects for soils enriched with animal manures might be reflected in any experiment involving a comparison of various fertilizers. Differences between continuous cropping and various cropping sequences always brings up the insect factor. The injury of wireworms and kafir ants to surface-planted crops emphasizes the need of entomology in the investigation of cultural systems.

Thus it is evident that soil entomology is an important phase of any agronomic practice. As Howard (5) has pointed out, many of our methods of farm practice encourage the multiplication and spread of many insects. In fact, we are fairly inviting them to overwhelm us. Why waste years of work trying to fight them in one way or another under existing conditions if it be possible, after a full understanding of their ways, so to vary crop methods as to hit a vital point in their economy without materially lessening crop production? A careful study by the agronomist of the facts already known about many of the principal soil-inhabiting insects will undoubtedly lead to a more practical and permanent type of agriculture.

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2Eb. THE RELATION OF FUNGI TO SOIL DETERIORATION[1]

L. R. Jones[2]

I. Successful plant cultivators, from the earliest times, have perforce been keen observers, and as such have noted the relation of certain variable environmental factors to crop failures and disease occurrence.

II. The chief variable factors so recognized fell naturally into two groups:

  (a) Aerial variables especially sunlight, rainfall, and temperature.

  (b) Soil variables.

III. The soil variables were at first vaguely interpreted in the general terms of fertility along with moisture relations, but lacked any exact data for clear analysis until the science of soil chemistry took form under Liebig's masterful leadership. This, however, tended to over emphasize the significance of chemical composition of the soil as a factor in crop diseases.

IV. Immediately following this the work especially of Pasteur and De Bary defined the relations of "germs" to fermentation and disease, giving secure basis for the complex modern sciences of plant pathology and soil biology.

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[1] Outline of discussion presented as a part of the symposium on "Soil Deterioration" at the meeting of the Society held in Chicago, Ill., November 16, 1925. This outline was amplified chiefly at two points. Of these the first dealt with the relation to plant diseases and the second to the development of disease-resistant plants both being illustrated with lantern slides. The essence of these arguments with some of the illustrations may be found in certain publications of the author and his associates, especially: The relation of environment to disease in plants, Amer. Jour. Bot., 11:601, 1924; Fusarium resistant cabbage, Wis. Agr. Exp. Sta. Research Bul. 48, 1924, and earlier publications there cited.

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V. I wish to pay my especial respects to those who have the courage, not to say the temerity, to try to find their way by methods of clear sustained thinking and sound laboratory researches through the mazes of soil biology, involving as these do perplexing and ever-changing variables.

VI. One reason for inviting attention to this is that we may in turn stress the two correlated statements:

  (1) Some of the most intricate problems in biology, unless it be in the field of soil biology, are in those aspects of plant pathology which deal with the fundamental questions of parasitism; questions which involve the intimate relations of parasite and host, two organisms living in enforced association, involving it may be a life and death struggle in correlated metabolic processes of nutrition or reproduction.

  (2) And in plant pathology some of the most complex of all problems are to be found among the soil-borne diseases, especially those involving root parasitisms. The reason is obvious since here we must face in combination the problems of the soil biologist on the one hand and of the student of parasitism on the other.

VII. There has been during the last third of a century, which is the period of more or less comprehensive and intelligent record of plant disease occurrence in the United States, a constant increase in both numbers and prevalence of serious soil-borne diseases and this increase is inevitably bound to continue indefinitely in the future.

VIII. The experience to date with these leads me to stress the importance of three things, having in mind at once the combination challenge to fundamental research and to effort at adequate control. Two of these are:

  (1) Constant vigilance against the careless introduction of such parasites into new territory and wider dissemination following such introduction.

  (2) Patiently persistent efforts in the long-time investigations of the relation of environment to the occurrence and severity of soil-borne diseases; the best progress in this being dependent on the coordinated efforts especially of the plant culturist and the soil biologist with the plant pathologist. Adequate understanding of these is essential as basic in the one hand to intelligent quarantine measures guarding against disease intro-

duction, and on the other to intelligent application of cultural practices to disease control following introduction of the parasites.

IX. The third thing which outweighs the others in practical significance and equals them in challenge to fundamental research concerns the problems of susceptibility and resistance to soil-borne diseases. The outstanding challenge coming from this insidious increase in soil-borne parasites is that we meet it by the one permanently satisfactory method of control for most such soil diseases, *viz.*, through developing disease resistant crops. We should frankly face the facts:

(1) Quarantine is merely delaying that which is practically inevitable in the world-wide distribution of all such parasites at least of our major crops.

(2) Once introduced such a parasite tends increasingly to develop and destroy proportional to its adaptation to local environmental conditions.

(3) Seed treatments are practically impotent and spraying methods almost wholly impracticable against soil-borne parasites.

(4) Soil sterilization is a most costly local palliative and only temporary at best.

(5) Crop rotation and soil management should be determined and directed by far more important considerations than those of disease avoidance. Such rotational programs involving important relations of soil fertility, soil physics, and economic expediency should not be distorted by the exigencies imposed by soil-borne diseases.

(6) The development of disease resistant crops is not only of especial importance in the case of soil-borne parasites but its practicability already has been proved with numerous examples.

X. The magnitude of this undertaking and its immanent importance combine to emphasize the conclusion that its advancement should not be left alone or even primarily to the plant pathologists. Still less may we hope that the plant geneticists may be numerous and free enough to help except incidentally. It should be the chief responsibility of pathologists and geneticists to define the problems and the methods, along with this of course contributing to the developments as they are able in particular cases. The need will be adequately met only through the combination of such efforts with those of horticulturists, agronomists, seedsmen, nurserymen, and especially the great numbers of plant cultivators, including especially amateur plant breeders.

XI. With such cooperation the possibilities are boundless and justify confidence that through developing disease resistant crop plants the future problems of soil-borne diseases will be adequately met.

2F. WASTE THROUGH SOIL EROSION[1]

M. F. MILLER[2]

Soil erosion through the action of wind and water is common to all soils. Speaking of water erosion particularly, it is one of Nature's great forces which shapes land surfaces and in large measure determines the character of soils. Left to herself Nature brings about a perfect adjustment between erosion losses, soil-forming processes, and the development of a natural flora. Erosion is, therefore, a normal, natural phenomenon which serves to renew soils by steadily bringing new soil material into the zone of soil development. It is only when man interferes with Nature's processes that erosion becomes a seriously destructive force. The removal of timber and the breaking up of prairie sods bring about greatly increased runoff of the water which falls. Floods increase and over large areas the surface soil may be removed more rapidly than Nature can replace it. As a result much land may be practically ruined while streams are choked with sediment, thus interfering not only with agriculture but with power development and navigation.

The National Conservation Commission[3] has estimated that of approximately ten million acres of abandoned land in the United States almost 40% of the abandonment has been the direct result of soil erosion. In a broad sense, therefore, soil erosion control has become a national problem, affecting not only agriculture but transportation, flood control, power development, and industry.

It is, of course, the influence of erosion upon farm land with which the agronomist is concerned and the injury which may result is well recognized. This is particularly true in the southern and southwestern parts of the corn belt and in most of the southern states where the nature of the rainfall, the topography of the land, the character of the soil, and the systems of agriculture combine to bring about excessive erosion losses Common observation is sufficient to convince anyone of the great damage which has resulted both from sheet erosion and from gullying in parts of these regions, yet the rate of loss as influenced by various governing factors has been given little study. Information has been limited largely to that gathered through observation or through measurements of material in solution and in suspension in streams Such stream data have been collected by many geologists and engineers from practically all of the important rivers of the world The data secured, when calculated as direct loss from the drainage basins, vary widely In some cases the loss is as low as 1 foot of soil removed in three or four hundred years, while in other cases the period reaches twenty-five thousand years. It seems safe to say that most rivers do not remove the soil from their drainage basins more rapidly than 1 foot in four or five thousand years. If such loss represented the average removal from agricultural lands it is evident that it would be negligible, so far as soil deterioration is concerned, but it must be remembered that in the early stages of erosion much material is removed from the higher to the lower levels that is not carried to the streams and on all exposed fields the losses are much greater than the average from the river basin as a whole

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[1] Paper read as a part of the symposium on "Soil Deterioration" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] Professor and Chairman of the Department of Soils, University of Missouri, Columbia, Mo.

[3] Senate Document 676, Vol. 1, 60th Congress, 2nd Session.

Data covering actual losses from definite areas of agricultural land and the comparative importance of influencing factors are very meager. It is with difficulty, therefore, that one is able to estimate the losses which are now taking place Sampson and Weyl,[4] working in the Manti National Forest in Utah, constructed catchment basins and for two years measured the loss from irregular, 10-acre tracts of grazing land They found that the amount of soil removed was correlated very definitely with the number and extent of torrential rains, the slope of the land, the cover as influenced by grazing, and the rapidity of flow of the runoff water The North Carolina Experiment Station has recently instituted an investigation in which the effect of different cropping systems on soil erosion is being accurately measured, but data have not yet been published.

The most extensive measurements of erosion losses, as influenced by various factors, are those of the Missouri Experiment Station begun in 1917.[5] These investigations are being carried out on a slope of 3.68%, which is doubtless not an excessive slope for average lands in the corn belt states. The soil is a rather poor phase of the Shelby loam, having a dark gray surface soil about 8 inches deep with a moderately heavy B horizon lying on glacial parent material containing scattered glacial pebbles. The surface 7 inches of the soil contains 0.112% of nitrogen, 0.058% of phosphorus, and 1.248% of potassium It has a productive capacity of a little under 30 bushels of corn in average seasons.

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[4] Range preservation and its relation to erosion control on western grazing lands. U. S. D. A. Bul. 675. 1918.

Table 1 compiled from the available data shows in summarized form the average result of 6 years' measurements with a rainfall of 35.87 inches as compared with a 34-year average at Columbia of 37.60 inches.

TABLE 1.—*Summary of erosion data covering six years.*
Missouri Experiment Station

Soil treatment or cropping system	Average percentage runoff	Total tons soil eroded per acre	Total surface inches of soil eroded	Number of years required to remove surface 7 inches
No crop, weeds removed when small	48 92	207.8	1.454	29
Spaded 4 inches deep, cultivated regularly	31.26	247.3	1.731	24
Spaded 8 inches deep, cultivated regularly	28.36	214.2	1.499	28
Continuous bluegrass sod	11.55	1.7	0.011	3,547
Continuous wheat	25.19	39.9	0.279	150
Rotation of corn, wheat, and clover	14.14	13.7	0.096	437
Continuous corn	27.38	106.5	0.745	56

The outstanding features of these data bearing on the quantitative measurement of soil loss may be summarized briefly as follows.

1. The largest loss from erosion under a cropping system is under continuous corn and the second largest loss under continuous wheat. Attention should be called to the fact that under continuous corn the surface 7 inches or so-called plow soil would be entirely removed even on this moderate slope during the average active life of a farmer who spends his whole life on the farm. On more sloping land the soil removal would necessarily be more rapid.

2. Continuous wheat, while holding the soil much better than continuous corn, allows a comparatively rapid removal. Moreover,

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[5] Duley, F. L., and Miller, M. F. Erosion and surface runoff under different soil conditions. Mo. Agr. Exp. Sta. Res. Bul. 63. 1923.

almost half of this loss takes place during the months of August and September after the land has been prepared for wheat and before the crop has made sufficient start to hold the soil. This has a direct bearing on the early preparation of land for this crop.

3. A crop rotation containing corn, a small grain, and a sod-forming legume is very effective in preventing excessive erosion loss, requiring in these experiments 437 years for the removal of the surface 7 inches.

4. The most effective crop in reducing erosion is sod in which case over 3,500 years would be required to remove the plow soil. Farmers all recognize the protective value of sod in erosion control, but these data seem to be the first which are available of the actual measurement of the influence of sod as compared to that of other crops. It must be recognized, of course, that in grass land erosion may show itself in the formation of gullies along cattle paths or water courses, and in these cases very large gullies often develop.

These investigations have also provided for certain determinations of the loss of plant nutrients. Naturally, such losses will depend not only upon the amount of soil removed but also on its composition. Table 2 shows the results of some of these measurements.

TABLE 2.—*Loss of plant nutrients through soil erosion.*

Missouri Experiment Station

Soil treatment or cropping system	Amounts removed in one year in pounds per acre			
	Nitrogen[a]	Phosphorus[a]	Calcium[b]	Sulfur[b]
No crop, weeds removed when small	98.88	47.47	379.38	100.85
Spaded 4 inches deep, cultivated regularly .	95.40	45.47	337.89	69.61
Spaded 8 inches deep, cultivated regularly	73.87	33.26	225.63	63.67
Continuous bluegrass sod	0.55	0.09	0.64	—
Continuous wheat	29.58	10.83	75.99	19.32
Rotation of corn, wheat, and clover .	5.94	2.22	41.47	6.98
Continuous corn	40.36	8.14	103.37	25.36

[a] Two-year average, Sept. 1, 1920 to Aug. 31, 1922.

[b] One year's results, Sept. 1, 1920 to Aug. 31, 1921.

In evaluating these data it seems evident that the losses of important plant nutrients through erosion may be considerable, especially where erosion is severe. It must be remembered, too, that the analysis of this soil shows it to be of only moderate potential fertility. On a more fertile soil the losses would be greater.

From the standpoint of the impairment of fertility, the nitrogen losses are undoubtedly the most significant, since this element is stored largely in the surface soil. The soil eroded annually from the cultivated and uncropped land carries approximately as much nitrogen as would be removed in the grain of a 100-bushel corn crop. In the case of continuous corn the nitrogen loss approximates that through the corn crop itself, which in these experiments has given an average yield of 28.8 bushels. Naturally, in the case of a more fertile soil with larger amounts of nitrogen the loss would be greater, although the corn yield would also be larger: It is probably safe to say that on land in continuous corn, with a moderate corn belt slope, the nitrogen loss through erosion approximates the loss through the crop, while on the steeper slopes it would be considerably larger.

In the case of continuous wheat yielding an average of 23.4 bushels in these experiments the nitrogen loss was approximately the same as that through the wheat grain. In the case of the rotation in which case the land was in wheat followed by clover during the two years under observation, the loss of nitrogen was greatly reduced. If it is assumed that the nitrogen lost the third year, when the land would have been in corn, would equal the loss of the nitrogen from the continuous corn plat, the average annual loss under rotation through the soil removed would be only about 17 pounds annually. One year's results have been secured on the losses of nitrogen as nitrate in the runoff water, but these losses seem too small to be of consequence in soil deterioration.

The losses of phosphorus, calcium, and sulfur are all significant, yet it must be remembered that there are almost as large stores of these elements in the under-soil as in the surface soil and sometimes larger. On the other hand, the readily available supplies of these elements, particularly of phosphorus, are doubtless largest in the surface soil so that these losses must have an important bearing on the decline of productivity. The fact that the losses of all of these elements equals or exceeds that through the crops commonly grown is an important consideration.

GENERAL CONSIDERATIONS

There is little doubt that in connection with erosion losses from agricultural lands the climatic factor is one of first importance both from the standpoint of temperature and of rainfall. The temperature is of influence in determining the number of months of the year when the ground is frozen, if it is frozen at all, while the degree of soil weathering is also materially influenced by temperature. In regions where the soil is frozen for two or three months of the year erosion is less than in the southern states where open winters prevail. The soils of the colder regions are usually less completely weathered, they are coarser in texture and therefore absorb water more readily than the soils of finer textures and more compact subsoils of the regions further south.

The influence of the rainfall is not limited to the amount of the precipitation, but its distribution is a very important factor. It is the torrential rains which do the most damage. In the Missouri measurements 14 rains out of 256 which fell during the six years under observation accounted for more than half of the soil lost from the land cropped to continuous corn and wheat and approximately two-thirds of that lost from the uncropped, cultivated land.

No accurate measurements are available of the influence of the texture of the soil on erosion losses, but observation, as well as theoretical considerations, point to soils of medium texture, such as silt loams, loams, and very fine sandy loams as most affected. When such soils are underlaid by heavy subsoils which prevent ready moisture penetration the conditions for excessive sheet erosion seem most favorable. In the case of gulleying the most favorable conditions seem to be those where the surface layers are of medium texture and the substrata made up of fine sand or sandy loam.

The influence of the cropping system is quite well indicated by the Missouri data. The outstanding conclusion, which also corroborates general observation, is that cultivated crops must be limited on all lands subject to destructive erosion. If the losses recorded are applied to the common corn belt system of farming, in which corn is the major crop, these losses are certainly much greater than can be offset by Nature and the farmer in processes of soil building. Moreover, these results apply merely to moderate slopes. When steeper slopes are concerned the losses are much greater.

EROSION AND SOIL AGE

Consideration thus far has had to do entirely with the destructive influence of soil erosion on agricultural lands. But it must be remembered that not all erosion is harmful. A certain amount is beneficial as a means of soil renewal or of keeping soils young. In the process of soil development soils age most rapidly where erosion losses are low. In such instances the constant weathering and leaching of the surface horizons in humid regions will ultimately so deplete them of basic materials and of phosphorus as greatly to reduce the fertility. Moreover, the extreme weathering of the soil material results in the generation of excessive quantities of colloids, which accumulate in the B horizon, producing a claypan, which further reduces the productivity of the land. This condition should be contrasted with that in which erosion is moderately active, and the removal of the surface layers is constantly bringing new soil material into the zone of weathering. Under such conditions excessive leaching of plant nutrients from the surface layer is not possible and an impervious B horizon does not have time to develop. The result is a comparatively young soil with greater potential fertility than that of the aged soil. It is, of course, true that excessive erosion may occur in the case of virgin soils where the land is naturally precipitous or in the intermediate stages of normal erosion. In such cases, as in the case of the land under the plow, the surface soils may be too shallow and the accumulation of organic matter too low to make possible a high degree of fertility. However, if a choice is to be made between virgin soils suffering from age because of insufficient erosion or from youth because of excessive soil removal, the choice, from the standpoint of potential fertility, must go to the young soil. It should be understood, however, that those virgin soils which are most fertile are those which have developed on comparatively recent deposits of soil material, such as glacial, loessial, or alluvial deposits and which have been subject neither to excessive erosion on the one hand nor to excessive leaching on the other. Such soils make up the most productive agricultural lands of the world.

THE INFLUENCE OF THE WIND

While this paper deals almost entirely with water erosion, a few words should be added regarding the influence of the wind upon the erosion and deposition of soil material. On the unprotected lands of semi-arid farms wind erosion may be just as injurious as water erosion on unprotected humid lands. The control of such erosion is one of the serious problems of the dry land farmer. In humid regions, however, it has little importance as a destructive agent. It is only in case of exposed sands that injury results from wind action. On the other hand, benefit may sometimes accrue through wind deposition of soil material. There is little doubt that the immediate surface layers of all humid soils are materially influenced by the wind. This, however, seems to be due more to the shifting of the soil material than to deposition proper. From the results of a rather large number of observations[6] in different parts of the humid region the evidence on this point seems fairly conclusive. In connection with the erosion measurements at Missouri, some records have been kept of wind deposited material in specially constructed dust collectors. Results show an accumulation of only about 250 pounds of mineral matter per acre annually. At this rate, about 8,000 years would be required to accumulate 7 inches of soil, while in the same field water erosion in a standard cropping system is removing the soil at the rate of 7 inches in a little over 400 years.

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[6] Free, E. E. The movement of soil material by the wind. U. S. D. A. Bur. of Soils Bul. 68. 1911.

THE FARMER MAY CONTROL THE SITUATION

It seems very evident from the data at hand that excessive water erosion is ruinous and that most agricultural lands of moderate to steep slopes in the corn and cotton belts are steadily losing fertility by this means. But it is also evident that most of this loss is due to mismanagement. The farmer has it within his power to control the situation if he will. The available data are fairly conclusive in showing that on lands of moderate slope a proper crop rotation will reduce the rate of soil removal to a point that its loss may be considered negligible. If such land loses no more than the surface 7 inches once in 400 years or even in half this time, as seems possible from the available data, little need be feared. The incorporation of organic matter through manuring, the use of deep-rooted legumes and sod crops, the action of earth worms in mixing the surface layers, and possibly the influence of deep-rooted plants in bringing mineral elements to the surface should go a long way in preserving the normal potential fertility of the soil. If with these are included the use of lime and mineral fertilizers, a high degree of productivity should be maintained. However, on the steeper slopes no such plans will answer. On such lands, terracing, contour farming, the use of sod crops, as well as careful methods of preventing gullying, will be necessary.

On the other hand, if the farmer continues to allow erosion to remove the surface soil as it is now being removed from the majority of corn and cotton lands, particularly in those regions most subject to torrential rains, a decline in productivity and the abandonment of lands will continue. The great difficulty, therefore, is that of influencing the farmer to adopt the necessary measures of erosion control. In spite of the best efforts of the various educational agencies which are working in behalf of agriculture, excessive erosion losses over large areas of the country are certain to continue for some time to come. Agronomists should realize more fully the great losses that careless farming is bringing about and intensify their efforts to secure a general adoption of control measures.

3A. SOIL DETERIORATION AND PUBLIC LAND POLICY[1]

RICHARD T. ELY[2]

For many years have the destruction and exhaustion of the soil been deplored by agriculturists and conservationists. In fact in 1791 George Washington wrote to Arthur Young a letter which stated the case for the American type of agriculture then and even to this very day,

> "The aim of the farmers in this country (if they can be called farmers) is, not to make the most they can from the land, which is or has been cheap, but the most of the labour, which is dear; the consequence of which has been, much ground has been scratched over and none cultivated or improved as it ought to have been: whereas a farmer in England, where land is dear, and labour cheap, finds it his interest to improve and cultivate highly, that he may reap large crops from a small quantity of ground."

At the Conference of Governors held 17 years ago some excellent papers were given calling attention to the disappearance of the soil's fertility and the excessive erosion of the land. Little was offered then in the form of a public policy to stop this waste of natural resources. However, Van Hise in his book the *Conservation Of Our Natural Resources* goes so far as to say, "As rapidly as a sentiment can be developed for their enforcement laws should be passed which will prevent the neglect of the land. The precautions necessary to prevent excessive erosion may be enforced by law since they vitally concern the common welfare not only of this but of all succeeding generations."

In this statement Van Hise suggests a policy of public control over private farms, that is far in advance of public opinion even at this time. On the other hand, we exercise a certain and increasing control over urban land through the various ways in which the police power manifests itself, but even in the case of urban land this control is not nearly so intensive as that suggested by Van Hise.

A glance at our past land policies will show that Van Hise's suggestion would have proved utterly useless in the past. Throughout our whole history, certainly up to 1900, the policy of the federal government and the individual states was to make land a free good. It is true that at first the federal government charged a nominal sum but this plan soon gave way to the "credit system," then came the preemption policy, and finally the homestead law was passed with its "farm for every one."

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[1] Paper read as a part of the symposium on "Soil Deterioration" at the meeting of the Society held in Chicago, Ill., November 16, 1925.

[2] Director, Institute for Research in Land Economics and Public Utilities, Northwestern University, Evanston, Ill.

Compared to land, labor was expensive, and it was only good management to economize the expensive factor and use the free factor liberally. When land is free, why save land? Since labor was dear American inventive genius created machines to save labor and to exploit the land on a still more magnificent scale. Gide has made the significant statement that after all machinery in itself cannot produce a single additional blade of grass.

The fact is that machinery has helped to make agriculture extensive, to produce food at extremely low costs, to export it by the millions of bushels and in the export ship nitrogen, potash, and phosphates to foreign lands.

The individual farmer was helpless in this era of "soil mining." The farmer who boasted that he knew how to farm because he had worn out three farms already was nearer the truth than we like to give him credit for. Sir Daniel Hall told us that after American competition depressed English agriculture the striking fact to the observer of farmers and their methods was that the good farmer with his well kept fields, with not a weed anywhere, excellent soil management, fine fences and barns was losing money, whereas his more "shiftless" neighbor who was more economical of his labor, was thriving. It is not the Belgian farmer who raises 50 bushels of wheat to the acre who is the competitor of the English farmer but the Australian dry farmer who gets but 10 or 12.

It is interesting to recall that from 1870 to 1900 there were seven or eight states in every decade which added at least five million acres apiece to our farm area. Under such a policy, for which the federal government, the states, and railways were responsible, it is no wonder that we had intense competition of farm with farm, and, like the rate wars among railways, we had bankruptcy not only of the farmer, but the farm itself in depletion of the soil elements and erosion of the lands.

All this has been condoned and even praised by some because this policy "developed" the country and there is no more magic word in our booster vocabulary than *development*! Capital is needed for this purpose and as Dr. Hess has shown, we turned our natural resources into capital to help the growth of our cities by furnishing them cheap food and cheap raw materials.

It is easy, of course, from this vantage point of time to criticize and say what we should have done. But I believe that the American spirit was such that no public policy of control over resources would have stood the test. It is interesting to recall that Edward Gibbon Wakefield actually had a plan of withholding the land of New Zealand and Australia and of settling it in an orderly manner, a plan that was tried to a very limited extent. Time will not permit me to elaborate this here and after all it is now chiefly of historical interest. It must be said to the credit of men like Washington and Jefferson that they also hoped for an orderly survey and settlement of the country with no such overrunning and exploitation as we have had.

It is also easy to say at this point in our history that we should have classified the land before allowing it to go into private hands, and then to have put each class of land to its best use. In the very nature and progress of settlement this was impossible. The lands of New England, and the Coastal states in general, less desirable than the great Mississippi Valley, had to be put under the plow before settlement could reach the "bread basket of America." Defense, health, and other factors often made necessary the clearing of hill tops which should be kept in forests if erosion is to be prevented. The land on the steep sides of the Appalachians should never have been cleared. J. Russell Smith[3] has so well pictured the effects of agriculture in Appalachia that I shall quote him here.

> "The Anglo-Saxon, with the level-land plow agriculture, brought from England, a land of gentle rain, entered the mountains, felled the fine trees of the rich forest, scratched the sloping earth with a plow and planted corn—corn, the great king crop of the level country,—the poorest crop of the hills. Before this mountain corn crop can ripen, it must be subjected to many rains. Unfortunately, the typical summer rain of the mountains is a tearing, pouring thunder-storm which lets loose on an acre of ground, one, two, three, and even four hundred tons of rushing water in a single hour. It is therefore natural that the earth should be washed away. After the earth has been deprived of its protection of forest and roots, the gashing and loosening by the plow and hoe seem to be a further special preparation for its complete removal by the rushing waters. The light, loamy soil which, if properly cared for, might nourish a thousand or ten thousand crops, is gone in a few seasons, and merely serves to choke the meadows below and to hinder navigation of the valley streams."

Only recently have we acted upon the relation between stream flow, erosion, and forests and have incorporated into a land policy the provision of protecting the headwaters of streams. In fact this was about the only purpose for which the federal government could acquire land for forestry purposes.

However, the farm land of the East was not only at a disadvantage by having to be created out of poor soils, but it later suffered from the pitiless competition of the West and gradually has sunk below the margin of agricultural land to its original state, and nature is reforesting it. But the private holder has suffered the consequences. Such a farmer, like his English cousin, could not hope to hold the land, much less to increase its fertility or even maintain it.

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[3] The World's Food Resources. New York: Henry Holt, 1919. (Page 545.)

This land is being scrapped so far as agriculture is concerned and this is as it should be; but some public policy of purchase for reforestation would ease the load the private owner has had to bear.

A proper economic survey is needed right now. The land suitable only for forests should be made more or less the property of the state or nation and be made to grow trees. Even a suitable taxation and forest fire policy will do much to encourage private initiative to undertake this work. Proper reforestation will do much to prevent erosion and restore the fertility of soils which if not "worn out" are at least tired of growing crops.

Much has been said about the soil depletion under the tenant system of farming as it is practiced in the United States. There is ample evidence to show that the tenant often lets the farm run to weeds, does little to prevent the erosion of the land and, worst of all, practices the kind of farming which will draw most heavily upon the soil elements. Tenant farming with us is extensive, one crop, short-term agriculture. While it is true that progress is being made in introducing livestock leases, we are many steps behind Great Britain in promoting the kind of tenant farming which will not merely keep up the fertility of the soil but actually increase it as has been the case in the older nations.

A policy which will guarantee a tenant remuneration for unexhausted fertilizers and improvements must be inaugurated in this country. It is interesting to note that a few years ago a bill with this end in view was introduced in the legislature of Illinois but it did not become a law. It is my belief, however, that we are not ripe for legislation at the present time. We must have further enlightenment of public opinion along with further experimentation before it is desirable to resort to legislation. It is encouraging, on the other hand, that we find so many landlords giving careful attention to the subject of conservation, and experimenting with various kinds of leases in order to maintain soil fertility.

However, both owner and tenant must become educated to the problem of soil improvement. As long as the owner himself looks upon the land as a speculative investment to be converted into cash by renting first and sale later, he will be a partner with the tenant in robbing the soil instead of conserving it. Significant in this respect is the interest shown in the maintenance and improvement of soil fertility at the last conference of landowners and managers at the University of Illinois. Professor Buechel of the Agricultural and Mechanical College of Texas writing in the July number of our *Journal of Land and Public Utility Economics* stresses this point saying that "the central aim of a leasing system should be to maintain a high productivity upon the farm."

Since the maintenance of the fertility of the soil depends to a large extent upon the fertilizer minerals a public policy must recognize this fact. Van Hise suggests the regulation of the mining of phosphates in such a manner that the low grade material will be available later and not be covered up or destroyed in getting out the better material. He suggests that all phosphate lands in the public domain be retained as public land and that the exportation of phosphate whether mined on public or private lands be prohibited.

Another change in public policy that is much to be desired is in the disposal of city sewage. With the growth of our cities the present disposal of sewage into streams and lakes ought to be unthinkable. Not only are we polluting the streams but we are losing valuable fertilizer materials.

As far as the conservation of the soil on the individual farm is concerned more can be done through education than compulsion. Public policy should encourage education along the lines of agricultural economics and land economics. Agricultural economics was late in making its appearance, and land economics is still newer. Public policy encouraging science will help in the maintenance of soil fertility.

In conclusion let me say that the Institute for Research in Land Economics and Public Utilities is engaged in researches along all of these lines. I bespeak your favorable consideration of the work that the Institute is doing and ask you all in the various ways that may occur to you to lend a hand. We are not a local organization, but national in scope and want to cooperate with all educational institutions and other agencies which aim at the improvement of farming conditions, as well as other conditions, which are connected with the utilization of the land.

3B. CROP PRICES AND SOIL DETERIORATION

G. F. WARREN

(Read by title only)

A FURTHER NOTE ON COMPETITION IN POTATOES[1]

George W. Musgrave[2]

The existence of competition in potatoes, observed in the 1923 plats in New Jersey, has been previously reported.[3] Data for the years 1924 and 1925 are now available and give some indication of circumstances under which provision must be made for the protection of the accuracy of results of field tests.

In the results previously referred to, a comparison of check rows alternating between plat rows in a size of seed piece experiment showed the yields of these rows to be depressed in the cases where such rows were adjacent to high-yielding plat rows. Plats consisted of 500-foot rows replicated to give a total of three plats of each treatment, or a total of 1,500 feet of row. In the work for the years 1924 and 1925 a rate of planting test was combined with the size of seed piece comparison.

In both the latter years the plats consisted of three rows each having a minimum net length of 100 feet, with rows spaced 34 inches apart. The fertilizer treatment consisted of 1,800 pounds per acre of a 4–8–5 mixture, and the seed was Maine-grown certified Green Mountain. In 1924 the series of plats was duplicated and in 1925 triplicated. In each year the replications were systematically distributed, although not in the same order both years. The arrangement, however, permits the comparison of border rows of the plats

Table 1.—*Plat treatments and yield, 1924.*

Plat	Size of seed piece	Spacing in the row, inches	Seed, bushels per acre	Yield, bushels per acre	Average yields by rate of seeding, bushels
A	½ ounce	12	8.25	132.35	132.35
B	½ ounce	9	11.00	155.41	142.65
C	1 ounce	18	11.00	129.89	
D	½ ounce	7½	13.20	149.25	145.47
E	1 ounce	15	13.20	147.14	
F	1½ ounce	22½	13.20	139.92	
G	½ ounce	6	16.50	164.91	154.94
H	1 ounce	12	16.50	156.29	
I	1½ ounce	18	16.50	143.62	
J	1 ounce	9	22.00	162.45	162.82
K	1½ ounce	13½	22.00	163.15	
L	1½ ounce	9	33.00	184.45	184.45

[1] Paper No. 261 of the Journal Series of the New Jersey Agricultural Experiment Station, Department of Agronomy, New Brunswick, N. J. Received for publication, November 25, 1925.

[2] Agronomist.

[3] Musgrave, Geo. W. Depression of check-row yields by adjoining high yielding plat rows in potatoes. *In* Jour. Amer. Soc. Agron., 16:633–635. 1924.

having similar treatments but being adjacent to either a higher or lower yielding plat, as well as comparisons between middle rows and outer rows.

The plat treatments and total yields for 1924 are given in Table 1. The yields are seen to increase in general with increasing *amounts* of seed applied. A comparison of the pairs of rows from the series available for the study of competitive influence is given in Table 2.

It has been shown that, in general, the larger sizes of seed piece produced a somewhat larger number of stems per plant. The work has also indicated that the larger rates of seeding have increased the yields, and observations in the field indicate that the higher yielding plats likewise have larger and more vigorous growing plants.

TABLE 2.—*Comparison of pairs of rows having same treatment, but adjacent to higher or lower rates of planting, 1924.*

Next to lower rate of planting		Next to higher rate of planting		Gain or loss
Plat	Pounds	Plat	Pounds	Pounds
D4	75	D6	71	4
E4	74	E6	73	1
F4	80	F6	65½	14½
G7	82½	G9	89	—6½
H7	78	H9	76	2
I7	70	I9	59	11
J12	84	J10	78	6
K12	84	K10	82½	1½
L12	85	L10	80½	4½
C15	61	C13	51	10
B15	84	B13	74	10
A15	64½	A13	67	—2½
F16	64	F18	68	—4
E16	57	E18	64	—7
D16	76	D18	61	15
I19	80	I21	73	7
H19	69	H21	70	—1
G19	72	G21	68	4
Totals	1,340		1,270½	69.50
Mean	74.44		70.583	3.86

$Z = \frac{3.86}{6.436} = 0.599$ $\sigma = 6.436$ Odds = 81.4:1

The mean yields of the pairs of rows having similar treatments but being adjacent to either a lower rate of planting or higher rate of planting plat are 74.44 pounds and 70.583 pounds, respectively. The odds calculated by Student's pairing method, as applied by Love[4], have been calculated as a test for the reliability of the comparison. The odds of 81.4:1 found above indicate that a real difference exists under the conditions of this test.

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[4] Love, H. H. A modification of Student's table for use in interpreting experimental results. *In* Jour. Amer. Soc. Agron., 16:68–73. 1924.

From the same data it is possible also to make a comparison of middle rows with border rows in an effort to determine whether sufficient protection from the competitive influence of adjacent plats is provided by a single border row. In Table 3, the middle rows are compared with an outer row having the same treatment but being adjacent to a larger rate of seeding. From the table it is seen that the mean yields of the middle and corresponding outer rows next to higher rate of planting plats are practically the same, being 69.67 pounds and 69.28 pounds, respectively; and the odds, calculated in the same manner as above, indicate that the chances are only 2.62:1 that a real difference exists.

TABLE 3.—*Comparison of pairs of rows having the same treatment. Middle rows with outer rows adjacent to higher rate of planting, 1924.*

Outer rows next to larger rate of planting		Middle rows adjoining rows of same rate of planting		Gain or loss
Plat	Pounds	Plat	Pounds	Pounds
A3	61½	A2	60	—1½
B3	70½	B2	70	— ½
C3	68	C2	64	4
D6	71	D5	78	7
E6	73	E5	83	10
F6	65½	F5	49	—16½
G9	89	G8	87	—2
H9	76	H8	74	—2
I9	59	I8	54	—5
C15	61	C14	59	—2
B15	84	B14	86	2
A15	64½	A14	70	5½
F18	68	F17	71	3
E18	64	E17	67	3
D18	61	D17	63	2
I21	73	I20	72	—1
H21	70	H20	77	7
G21	68	G20	70	2
Totals	1,247		1,254	15½
Mean	69.28		69.67	.85

$Z = \frac{.85}{5.646} = 0.15$ $\sigma = 5.646$ Odds = 2.62:1

Likewise, it is possible to compare middle rows with the corresponding outer rows having the same treatment, but being adjacent to a plat having a smaller rate of seeding. This is given in Table 4. From this table it is seen that the outer rows yielded 74.97 pounds compared with 74.75 pounds from the middle rows, the odds being but 0.96:1 that a real difference exists. This would seem to indicate that sufficient protection was provided by the single outer rows under these conditions.

In 1925 a similar series of plats provided data for the same com-

TABLE 4.—*Comparison of pairs of rows having the same treatment. Middle rows with outer rows adjacent to lower rate of planting, 1924.*

Outer rows next to smaller rate of planting		Middle rows adjoining rows of same rate of planting		Gain or loss
Plat	Pounds	Plat	Pounds	Pounds
D4	75	D5	78	—3
E4	74	E5	83	—9
F4	80	F5	49	31
G7	82½	G8	87	—4½
H7	79	H8	74	4
I7	70	I8	54	26
J10	78	J11	83½	—5½
K10	82½	K11	71	11½
L10	80½	L11	93	—12½
F16	64	F17	71	—7
E16	57	E17	67	—10
D16	76	D17	63	13
I19	80	I20	72	8
H19	69	H20	77	—8
G19	72	G20	70	2
L22	93	L23	100	—7
K22	74	K23	74	—
J22	64	J23	79	—15
Totals	1,349½		1,345½	14
Mean	74.97		74.75	.78

$Z = \frac{.78}{15.457} = 0.05$ $\sigma = 15.457$ Odds = 0.96:1

TABLE 5.—*Plat treatments and yield, 1925.*

Plat	Size of seed piece, ounces	Spacing in row, inches	Seed, bushels per acre	Yield, bushels per acre	Average yield by rate of seeding, bushels
A	½	12	8.25	87.984	87.98
B	½	9	11.00	151.893	122.50
C	1	18	11.00	93.123	
D	½	7½	13.20	156.510	122.20
E	1	15	13.20	116.667	
F	1½	22½	13.20	93.447	
G	½	6	16.50	169.947	131.15
H	1	12	16.50	126.81	
I	1½	18	16.50	97.91	
J	1	9	22.00	138.069	134.57
K	1½	13½	22.00	131.076	
L	1½	9	33.00	154.80	154.80

parisons, but for a growing season decidedly unfavorable for potatoes. The average yields for the central New Jersey potato region were reduced by nearly one-half of the normal crop for the state as a whole, averaging 94.1 bushels as compared to 156 bushels for the preceding year. The plat yields as a whole were also affected by the season and considerably reduced in yield. It was a matter of interest then to determine whether, under these conditions, competition existed between the plat rows.

Plat treatments and yields for 1925 are given in Table 5.

The average yields for the various quantities of seed are again seen to increase in general with increasing *amounts* of seed and 12 pairs of rows available for comparison are arranged in Table 6.

TABLE 6.—*Comparison of plats having the same treatment, but adjacent to higher or lower rates of planting, 1925.*

Next to lower rate of planting		Next to higher rate of planting		Gain or loss
Plat	Pounds	Plat	Pounds	Pounds
J 1-1	54	J 1-3	49	5.0
L 1-1	65.5	L 1-3	65	.5
B 2-1	76	B 2-3	66	10.0
C 2-1	53	C 2-3	47.5	5.5
D 2-3	36	D 2-1	49	—13.0
F 2-3	46	F 2-1	38	8.0
H 2-3	57	H 2-1	56	1.0
I 2-3	48	I 2-1	47	1.0
J 2-1	60	J 2-3	69	—9.0
L 2-1	70	L 2-3	63	7.0
B 3-1	46	B 3-3	60	—14.0
C 3-1	30	C 3-3	48	—18.0
	641.5		657.5	—16.0
Mean	53.46		54.79	—1.33

$Z = \frac{-1.33}{9.2163} = -0.14$ $\sigma = 9.2163$

Odds = 2:1 in favor of rows next to higher rate of seeding.

TABLE 7.—*Yields of rows omitted from Table 6.*

Plat	Next to lower yielding plat Pounds	Next to higher yielding plat Pounds
K-1	49	54
K-2	84	69
A-2	56	44
A-3	38	28
E-2	52	46.5
G-2	54	56
Totals	333	297.5
Average	55.5	49.6

From Table 6 rows K-1, K-2, and E-2, lying between plats B and H, and rows A-2, A-3, and G-2, lying between plats D and J, have been omitted, but are given in detail below, since the yields of the marginal plats B and H and D and J are not in order of rate of seeding. Arranged as to *yield* of marginal plats, these rows are given in Table 7.

If included in Table 6, the mean yield of plats next to the lower yields is 54.1 pounds and plats next to the higher yield 53.05 pounds, with odds of 2.2:1. If excluded from Table 6, the mean yield of the plats adjacent to the lower yielding ones is 53.46 pounds and adjacent to the higher yielding ones 54.79 pounds, with odds of 2:1 in favor of the higher rate of seeding. In either case, the odds are insignificant and it is apparent that no evidence of competition is to be found under the conditions of this test.

SUMMARY AND CONCLUSIONS

Data on competition for the three years of 1923, 1924, and 1925 indicate that for the two former years yields of rows adjacent to rows of high-yielding plats were depressed. For the year 1925, when yields were much below normal, no evidence of competition appeared. Comparison of middle rows with border rows for the year 1924 indicated that, where border rows were influenced in yield according to whether the adjacent plat rows were high- or low-yielding ones, middle rows were not appreciably influenced by the same conditions.

It is concluded that, since in certain years at least, competition appeared under the conditions of the test where row spacing, fertilizer application, soil conditions, etc., were the same as commonly used in the central New Jersey potato region, single row plats are inadvisable in experimental work under these conditions, and that at least one border or buffer row should be used on the margins of such plats.

QUANTITATIVE METHODS IN SOIL SURVEY WORK[1]

R. S. SMITH[2]

The birth of an essentially new concept of the soil within very recent years has made it clear to the soil surveyor that he is facing new problems of observation, measurement, and description. This new concept of the soil as a natural body made up of parts, the characteristics of which are the result of the interaction of forces within the soil mass and external to it, has come about very largely through the study of soils as they occur in the field.

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[1] Contribution from the Agronomy Department, Division of Soil Physics, University of Illinois, Urbana, Ill. Received for publication December 10, 1925.

[2] Chief in Soil Physics and Soil Survey Mapping.

The new soil concept requires that soils be studied, classified, correlated, and described on the basis of soil character. It is true that in field work it is not possible to do this as completely as is desirable; yet, now that the soundness of the principle is established, practice is bound to follow. The acceptance of this principle makes it essential that, in addition to qualitative observation, methods of quantitative measurement be developed which can be applied to the characters upon which the differentiation of soils is based. Ability to observe is increasing; however, it is probably true that there are many observable soil characters which are not yet seen. The ability to observe comes only from long effort and work with the object under study. The first problem, then, in the field study of soils is to see what is there.

The second problem is to develop methods for measuring the things seen. It seems that no argument is needed to support the statement that the facts observed must be measured if they are to be tangible and recordable. Quantitative statement is demanded by science, and certainly no study can make claims to being scientific unless its facts can be stated in quantitative terms. Unless the facts observed, in this case the soil characteristics, can be recorded, they cannot form a usable body of information. David Starr Jordan in a recent paper in Science emphasizes "the expression of the individual facts in tangible and recordable form."

The third problem is to interpret the observed and recorded facts It seems clear that the science of soil classification, if this expression may be used, is not yet in a position to enter upon this portion of its task to any great extent. Before it can successfully be undertaken, the intangible must be reduced to the tangible by quantitative methods. Interpretation cannot precede the understandable statement of the facts to be interpreted and such statement is dependent on terms having a definite and quantitative meaning.

Certain soil characters can probably now be given sufficiently precise quantitative statement. These characters are: Texture, if it be assumed that mechanical analysis portrays the true physical composition of a soil; structure; depth of horizons or strata; and relative position of strata. The problem in connection with the structural characteristics of a soil is one of recognition. The need here is for a better understanding of the various possible structures. As soon as this understanding is reached, it will be possible to see and to describe in a precise and understandable way the various structures encountered. The natural and inevitable outgrowth of such descriptions will be the adoption of a single term to describe each structural condition. The present paucity of such terms and the lack of a clear understanding of the meaning of those now in use is the result of failure, as yet, to recognize clearly the structures which exist. It does not appear that there is reason to fear the use of a single term, such as nut or crumb, to designate a structural condition, because such terms must follow and not precede recognition and description.

There is another group of soil characters which belongs in a different category from those mentioned above. These characters cannot now be adequately stated either by the descriptive method or by the use of designating terms. Included in this group are such characters as color, plasticity, and compaction.

Color is one of the essential soil characters always observed and an attempt is always made to record it. The problem in connection with color does not consist simply in identifying colors and designating them by name or by number. While it is not yet possible to do even this, it is anticipated that a practicable method for doing it will soon be developed. There are apparently more difficult problems in connection with the color of soils than with that of identification. The soil horizons in humid regions, particularly the lower ones, are variegated in color; that is, the predominant color is spotted, streaked, or marked with areas of varying size and regularity having a different color. The term "mottled" is used to describe at least certain phases of this condition. The use of this term, however, is so broad that it really has little meaning. The proportion of the various colors is a matter of importance. For example, a gray substratum spotted with yellow probably indicates a very different condition from a yellow substratum spotted with gray, but both conditions are spoken of as mottled. The requirements in soil study demand that, in addition to having a method for identifying and naming colors, there shall be some practicable method of determining and recording the proportion of the variously colored areas which make up the horizon section. In order to do this there must be, of course, a practicable method for measuring colors.

Another problem, or perhaps a lack of agreement, in connection with color is how the color of a soil should be observed. Is it the color of a freshly broken face in the moist or air-dry condition that should be recorded, or is it the color of the particular spot in the broken face after it is rubbed lightly? Is it not unusual for the freshly broken faces of the A_1 and A_2 horizons to have the same color appearance, but when these faces are lightly rubbed, a difference becomes apparent. When the color of the freshly broken face is observed, what is seen is the thin coating on the granules or cleavage planes and not the color of the interior of the mass. Much further study is needed on this phase of the problem

It seems, therefore, agreement must be reached as to how soil color should be observed, and then there must be adopted a method for measuring and recording color and for determining the proportion of the various colors which compose the soil mass.

After the problems of measuring and recording color have been solved, then other color problems, such as genesis and seasonal changes, may be successfully studied. The problem of the genesis or origin of soil colors is intimately bound up with the relative influence of parent material and weathering processes on color. Gray mottling may be due primarily to character of parent material, or it may be due primarily to the environmental conditions under which the weathering forces have acted. Seasonal color changes, as well as color changes due to varying moisture contents, are not unusual. In southern Illinois, there is, in the aggregate, a considerable area which has a subsoil beautifully mottled with orange-red, if seen in the fall. The brilliant orange-red color is replaced by a dull brick-red in the spring. This change is brought about by a change in environmental conditions, and its proper interpretation might provide a bit of evidence regarding soil development. A color change, such as the one noted, is a source of confusion, particularly to one who is not familiar with the region, and it illustrates the necessity for a thorough acquaintance with the soils of the region being worked which can come only through a long and intensive study.

Plasticity is another soil character which is observed. An attempt is made to record the degree of plasticity by the use of such terms as "highly plastic" or "slightly plastic." However, there is no method for determining degree of plasticity. A number of methods have been proposed for measuring this property, but none of them is satisfactory for measuring the plasticity of a soil. It may be that it will have to be measured indirectly by measuring the amount of the constituents present which are mainly responsible for imparting plasticity. Certainly the methods for its direct measurement now in existence do not lend much encouragement to the hope that the correct method of attack has been devised.

Another important soil character is compaction. Qualitative differences in compactness are easily discerned by differences in penetrability. This is a property which changes greatly with relatively small moisture change. It is a property which has received much study and several methods have been proposed for its measurement. It is still necessary to depend on judgment as to degree of penetrability, and judgment varies not only with the moisture condition of the soil, but also with the hotness of the sun and the number of holes which have been dug.

It is not the purpose of this paper to discuss all of the soil characters which need study, looking toward the establishment of quantitative bases for their statement, but rather again to call attention to the necessity for a quantitative basis for the statement of every character used. If the things which are seen and upon which differentiations in soil mapping are based are intangible and must remain so, the classification and correlation of soils must remain an art and cannot become a science. An important part of the job of the soil surveyor is to identify soils. If his identification is to be consistent and his descriptions usable, the observable characters which he uses must be reduced to a quantitative basis and their precise statement made possible. It is safe to predict that the splendid progress made in the study of soils during the past few years will be equaled and exceeded during the next few years because the quantitative methods upon which progress depends will be developed now that their importance is realized by soil survey men.

NOTES

Following the suggestion of several members of the Society and in accordance with the practice of several other scientific journals, the Editor has decided to open a new section in this JOURNAL, to be known as "Notes." For use in this section, he will be glad to receive short articles describing interesting field observations, laboratory experiences, new technics, or any items of interest to agronomists, which in themselves are not such material as would justify a formal paper, or scientific contribution, but which will be useful to other workers in this field.

It will be the plan not to include in such "Notes" any literature citations, unless the matter in question is directly pertinent to or a discussion of some preceding article. Reprints of "Notes" will not be furnished to authors unless specifically requested at the time when the manuscript is submitted. Proofs will not be sent to authors for correction (unless specially requested), as it will be assumed that the matter is in final form for publication when received and the editorial office will assume responsibility for typographical accuracy.

In the past, such "Notes" have been included from time to time in the section known as "Agronomic Affairs;" but it seems to be wise and desirable now to recognize as a definite feature of the JOURNAL these "Notes" as coordinate with "Book Reviews" and "Agronomic Affairs."

As illustrations of the type of material which may be used in the new section, members of the Society are referred to the "Note Concerning the Occurrence of Johnson Grass as a Weed in Ohio" in the November, 1925, issue, and the two similar notes in the December issue.

Subject to the limitations imposed by making each issue a multiple of eight pages, it will usually be possible to publish a "Note" in the next or second issue of the JOURNAL after it is received by the Editor.

The section under the general heading of "Agronomic Affairs," which has been known in the past as "Notes and News," will in the future be designated as "News Items," and correspondents are urged to send timely news items for use therein.

AGRONOMIC AFFAIRS

NEWS ITEMS

George W. Musgrave, Head of the Agronomy Department of the New Jersey Experiment Station, has been granted a year's leave of absence beginning February 1. He will organize and head the new Agricultural Department of the American Cyanamid Company, with offices at 511 Fifth Avenue, New York City. The work of the new department will be mainly research, and will be largely confined to the agricultural regions east of the Mississippi.

At the Ohio Agricultural Experiment Station at Wooster, on September 1 last, R. M. Salter, formerly of Ohio State University, was appointed Chief of the reorganized Department of Agronomy which includes the work of the former departments of agronomy, soils, and chemistry. The new department consists of the following members in addition to its chief: C. E. Thorne, J. W. Ames, F. A. Welton, L. E. Thatcher, J. B. Park, F. E. Bear, and C. W. Conrey.

President Albert F. Woods, of the University of Maryland, has been appointed Director of Scientific Research in the United States Department of Agriculture, succeeding E. D. Ball, who resigned some months ago. President R. A. Pearson, of Iowa State College, has been appointed to fill the vacancy at the University of Maryland. These changes are effective about April first.

ERRATUM

In Volume 17, No. 11, pages 689 and 690 of this JOURNAL, the legends for the cuts of Figures 5 and 6 are interchanged.

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AMMONIFICATION IN RED PRAIRIE SOILS[1]

HENRY F. MURPHY[2]

INTRODUCTION

Ammonification studies are important at least from one standpoint, namely, that of showing the rate of decomposition of the cruder organic nitrogenous materials into a more available form of nitrogen for plant use. The ammonia produced, though it may be made use of by some plants as such, is ready to be taken by the nitrifiers and changed into a nitrate, which form most plants prefer.

LITERATURE REVIEWED

Peck (7)[3] found that the addition of lime as carbonate, sulfate, or phosphate stimulated ammonification in some soils of Hawaii.

Stephenson (9), in studying ammonification in a silt loam soil which was fairly well supplied with organic matter and a sandy loam rather low in organic matter, found that ammonification was greater in the absence of lime on both acid soils. A possible explanation for the difference was the soil flora.

Murray (6) found that when straw exceeded 0.9% it inhibited ammonification.

Vandecaveye (10) reports results showing that manure and lime stimulated ammonification in Carrington loam soil Manure alone, however, slightly depressed ammonification.

Voorhees, Lipman, and Brown (11) report studies showing that ammonification was promoted by previously liming box soils of sandy loam and red shale soils.

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[1] Contribution from the Department of Agronomy, Oklahoma A. & M. College, Stillwater, Okla. Received for publication November 27, 1925.

[2] Associate Professor. The writer wishes to make acknowledgment to D. R. Johnson, who started this work and carried it on until 1920; and to others who assisted in the chemical work.

[3] Reference by number is to "Literature Cited," p. 183.

Brown (1) reached the conclusion that applications of lime up to 3 tons per acre increased ammonification as measured by the beaker method, a method considered satisfactory for the test.

Fischer (4) observed that organic substances checked ammonification to a marked extent.

Kelley (5) reports results showing that ammonification was much more active in untilled soils than nitrification. Calcium carbonate produced considerable stimulation of ammonification of dried blood and cottonseed meal in some soils, but in others it had little effect.

Brown (2) reports that the ammonifying power, nitrifying power, and in some cases, the nitrogen-fixing power of some soils may indicate the crop-producing power, or at least the relative crop-producing power of these soils.

Burgess (3) concludes that ammonification tests are not suitable guides to the fertility of average Hawaiian soils, although they often show differences between very poor and very good soils.

EXPERIMENTAL WORK

SOILS STUDIED

The two predominating upland soil series of the Red Prairies are the Vernon and Kirkland. These soils are residual, largely from red sandstone and shale.

The Vernon soil is chocolate red in the surface and subsoil, although the upper subsoil often is a brownish color. The subsoil is sandy clay to a stiff clay. The topography is rolling to steep. Good drainage is the general rule with this soil.

The Kirkland soil is chocolate brown in the surface with slightly lighter colored subsoil. The subsoil, in some cases, is more or less mottled, due to the fact that it is of a hard-pan nature and does not permit of good under-drainage. This series occupies the nearly level areas.

ARRANGEMENT OF PLATS

Vernon very fine sandy loam was the type used to represent the Vernon soils and Kirkland loam was used for the Kirkland soils. Both soils were typical of their respective series.

Each of these plats were 1/20 acre in size (124.45 x 17.5 feet). The materials, as given in the table, were applied in the spring of 1917, and also in the spring of 1921.

A border 7 feet wide separates the Kirkland soil plats from each other, while the Vernon plats are separated by borders 3 1/2 feet wide.

TABLE 1.—*Fertilizer plan for both soils.*

Plat	Treatment
1	Check
2	5 tons ground limestone
3	2.8 tons calcium oxide
4	5 tons ground limestone+8 tons manure
5	2.8 tons calcium oxide+8 tons manure
6	Check
7	3 tons ground limestone
8	1.68 tons calcium oxide
9	3 tons ground limestone+8 tons manure
10	1.68 tons calcium oxide+8 tons manure

METHOD OF PROCEDURE

Except where otherwise noted, samples of soil were collected from each of the plats of the two soils during June, July, and August for

TABLE 2.—*Showing milligrams of ammonia per 100 grams of Vernon soil.*

Plat	1918	1920	1921	1922	1923	1924	Average
				June			
1	90	103	69	123	—	122	101
2	96	95	68	128	—	189	115
3	75	61	136	104	—	162	108
4	54	74	146	92	—	227	119
5	94	73	126	88	—	228	122
6	88	91	114	78	—	170	108
7	125	45	128	132	—	197	125
8	118	30	159	93	—	202	120
9	104	43	119	74	—	200	108
10	124	28	150	99	—	98	100
				July			
1	—	81	125	244	314	253	203
2	—	93	152	376	251	377	250
3	—	98	113	362	334	371	255
4	—	66	121	327	302	308	225
5	—	51	117	277	244	258	189
6	—	114	68	289	247	232	190
7	—	117	110	220	291	246	197
8	—	47	101	260	254	373	207
9	—	71	133	296	267	317	217
10	—	102	116	232	254	335	208
				August			
1	90	112	82	103	64	120	95
2	114	110	126	165	96	200	135
3	104	86	115	269	105	176	142
4	119	97	153	199	97	160	137
5	97	134	115	172	87	—	121
6	85	78	72	98	52	—	77
7	101	115	64	143	90	198	119
8	127	112	104	196	102	149	132
9	117	131	111	193	96	125	129
10	106	139	137	113	76	97	111

the years 1918 to 1924, inclusive. The samples were taken from an area 10 in. x 20 in. x 6 in. deep for each plat at each sampling time, but not at the same place any two sampling times for the same year. This distributed the samples over each plat for each year. The soil was dug by means of a sterilized spatula, thoroughly mixed, placed in a sterilized can, and taken to the laboratory where a moisture determination was made of a representative of the sample. The remainder was used for making the ammonification and other tests.

For the ammonification test, duplicate samples of soil of 100 grams (dry basis) from each plat were placed in sterilized glass tumblers. To each tumbler was added 5 grams of dried blood. The sample was then thoroughly mixed and raised to optimum moisture content for the respective soil with an additional 12 cc. of water for the dried blood. The samples were then incubated for one week at room temperature. At the end of this time the ammonia was determined by the aeration method as recommended by Potter and Snyder (8). The results are given in Table 2.

It is evident from Table 3, that the heavy application of lime produced more ammonia than the lighter application; that manure in

TABLE 3.—*Showing a general average ammonification per season for the different treatments on Vernon soil in milligrams per 100 grams soil.*

Soil treatment	June, 1918–1924, 6-year average	July, 1920–1924, 5-year average	August, 1918–1924, 6-year average	Average per season
5 tons $CaCO_3$ or equivalent CaO	111	253	139	168
5 tons $CaCO_3$ or equivalent CaO + manure	120	207	129	152
Average of heavy lime treatments	116	230	134	160
3 tons $CaCO_3$ or equivalent CaO	123	202	125	150
3 tons $CaCO_3$ or equivalent CaO + manure	104	212	120	145
Average of light lime treatment	113	207	123	148
Average of all $CaCO_3$ treatments (no manure)	120	223	127	157
Average of all CaO treatments (no manure)	114	231	137	161
Average of all check treatments	105	197	86	129
Average of all $CaCO_3$ treatments with manure	113	221	133	156
Average of all CaO treatments with manure	111	199	116	142
Average of all limestone treatments	117	222	130	156
Average of all CaO treatments	112	215	127	151
Average of all manure treatments	112	215	125	150

TABLE 4.—*Showing the general averages of ammonification in milligrams per 100 grams of soil for the three months during the period, 1918–1924 on Vernon soils.*

Plat	Treatment	General average, 1918–1924, inclusive
1	Check	133
2	5 tons $CaCO_3$	167
3	2.8 tons CaO	169
4	5 tons $CaCO_3$+8 tons manure	160
5	2.8 tons CaO+8 tons manure	144
6	Check	125
7	3 tons $CaCO_3$	147
8	1.68 tons CaO	153
9	3 tons $CaCO_3$+8 tons manure	151
10	1.68 tons CaO+8 tons manure	140
	Average of checks	129

TABLE 5.—*Showing the number of milligrams of ammonia per 100 grams of Kirkland soil.*

Plat	1918	1920	1921	1922	1923	1924	Average 1918–1924
			June				
1	70	128	96	28	118	73	86
2	34	123	129	66	119	132	100
3	81	143	115	53	99	161	109
4	79	105	128	23	106	122	94
5	84	133	120	40	127	157	110
6	77	113	152	56	87	102	97
7	43	162	125	90	181	86	97
8	81	142	114	38	37	119	89
9	95	65	182	46	61	126	96
10	98	116	152	34	85	103	96
			July				
1	—	93	65	102	518	265	208
2	—	58	166	157	479	282	228
3	—	91	148	141	530	255	233
4	—	79	104	173	436	241	206
5	—	97	127	121	469	294	222
6	—	82	123	142	477	252	215
7	—	88	157	120	515	186	213
8	—	107	185	131	509	222	231
9	—	95	185	151	544	240	243
10	—	82	145	138	470	195	206
			August				
1	118	54	86	159	78	271	128
2	88	—	117	172	131	218	145
3	133	17	152	204	106	373	164
4	73	54	130	163	188	320	141
5	133	50	125	211	96	210	138
6	83	39	136	160	89	326	139
7	80	30	197	143	114	370	141
8	120	39	151	188	125	294	153
9	111	31	169	193	79	329	152
10	124	29	157	166	122	321	153

connection with lime did not increase ammonification; and that any of the averages were higher in ammonia than the check plats.

TABLE 6.—*Showing a general average ammonification per season for the different treatments on Kirkland soil in milligrams per 100 grams of soil.*

Soil treatment	June, 1918–1924, 6-year average	July, 1919–1924, 5-year average	August, 1918–1924, 6-year average	Average per season
5 tons $CaCO_3$ or equivalent CaO	104	231	155	163
5 tons $CaCO_3$ or equivalent CaO+manure	102	214	139	152
Average of heavy lime treatments	103	222	147	158
3 tons $CaCO_3$ or equivalent CaO	93	222	147	154
3 tons $CaCO_3$ or equivalent CaO+manure	96	225	153	158
Average of light lime treatments	94	223	150	156
Average of all limestone treatments (no manure)	99	221	143	154
Average of all CaO treatments (no manure)	99	232	158	163
Average of all check treatments	92	212	133	146
Average of all limestone treatments with manure	95	225	147	155
Average of all CaO treatments with manure	103	214	146	154
Average of all limestone treatments	97	223	145	154
Average of all CaO treatments .	101	223	152	159
Average of all manure treatments	99	219	146	155

Table 4 shows that the heavy application of lime produced more ammonia than the lighter application, and that CaO was slightly more efficient than $CaCO_3$

TABLE 7.—*Showing a general average ammonification in milligrams per 100 grams of soil for the years 1918 to 1924, inclusive, in Kirkland soil.*

Plat	Treatment	General average, 1918–1924, inclusive
1	Check	141
2	5 tons $CaCO_3$	158
3	2.8 tons CaO	169
4	5 tons $CaCO_3$+8 tons manure	147
5	2.8 tons CaO+8 tons manure	157
6	Check	151
7	3 tons $CaCO_3$	150
8	1.68 tons CaO	157
9	3 tons $CaCO_3$+8 tons manure	164
10	1.68 tons CaO+8 tons manure	152
	Average of checks	146

Table 6 shows that the heavy application of lime produced more ammonia than the light application; that CaO produced more ammonia than $CaCO_3$; that manure in connection with lime did not produce any more ammonia than lime alone; and that the average of any of the treatments was higher than the check plats.

Table 7 shows that manure depressed ammonification, except with the lighter application of $CaCO_3$; that the heavy application of lime produced more ammonia than the light application; and that CaO produced more ammonia than $CaCO_3$.

SUMMARY

1. The general tendency was toward an increase in ammonification from the use of either CaO or $CaCO_3$ on either soil.
2. Manure as a rule did not increase ammonification to any appreciable extent above that of lime. In some cases, manure seemed to have a depressing effect on ammonification.
3. The heavy application of lime produced more ammonia than the light application.
4. CaO as a rule was slightly more favorable toward ammonification than $CaCO_3$.

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RELATION OF SOIL MOISTURE CONTENT TO RESISTANCE OF WHEAT SEEDLINGS TO LOW TEMPERATURES[1]

K. H. Klages[2]

INTRODUCTION

An extensive literature has been compiled on the relation of low temperatures to plant growth; yet many factors involved in the freezing of plants, and especially in the injury to cultivated crops, are still wanting an explanation. No conclusive investigation has so far been reported on the relation of soil moisture content to the freezing of young wheat plants. Many factors involved in the killing of plants by low temperatures are beyong the control of man. It must be granted, however, that any information concerning the physiological behavior of plants toward factors modifying the degree of injury will be of value in the final solution of the problem.

EXPERIMENTAL WORK

MATERIALS AND METHODS

Wheat seedlings were grown in 2-quart, wide-mouthed Mason jars on quartz sand, the surface soil of brown silt loam, and of clay with four different moisture contents, namely 20, 30, 40, and 50%. The moisture contents were based on percentage of saturation. Care was exercised to have equal amounts of soil and the same degree of compactness in each container.

Since it was necessary to have all seedlings in the soils of different moisture content come up at the same time, so as to eliminate the effect of variation in the age of the individual plants under investigation, it was found best to plant seeds soaked in water from 8 to 12 hours previous to planting. A number of containers in excess of the number required for any given experiment were always provided so that those with a uniform growth of plants could be selected. The number of plants in each container varied from 8 to 12. Considerable difficulty was encountered in securing this number of plants on the higher moisture soils. For this reason 50% was the highest moisture content used. To keep down evaporation the containers were sealed with paraffin immediately after planting. Covering the jars with a thin layer of sand was found unsatisfactory, the chief objection being that water added to maintain a constant weight could not be evenly distributed throughout the soil in the low moisture series.

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The seedlings were subjected to freezing temperatures when 4 to 5 inches high, at the time the third leaf began to appear, which was in most cases 10 to 14 days after planting. Through courtesy of the Dairy Department, their refrigerator, with a temperature range of from –13° to –21° C., was used for the freezing. This temperature was lower than would have been most desirable, yet it is believed that comparative results were obtained.

Since injury from low temperatures is dependent as much on the duration of the freezing as on the actual temperature depression, it was necessary to determine the length of time that the plants could be exposed to the given temperature. After some preliminary work an exposure of from two to three hours was decided upon, depending on the age of the plants and on the temperature which varied from day to day. No attempt was made to harden the plants prior to the exposure. They were taken directly from the greenhouse with an average temperature of around 18° C. and were returned to the greenhouse upon removal from the refrigerator. Care was taken to keep the thawing plants out of direct sunlight in order to guard against too rapid evaporation from the injured tissue.

Three different varieties of wheat were used, namely, Turkey Red, Mediterranean, and Marquis.

The percentage of killing was determined one week after the exposure. Plants not showing signs of life after that time were designated as dead.

RELATION OF SOIL MOISTURE CONTENT TO RESISTANCE TO COLD

Experiment No. 1.—Turkey Red on quartz sand.—The plants were exposed to the low temperatures given in Table 1 for 15 minutes to 2 hours and 30 minutes.

Table 1 shows that killing begins early on the medium moist and moist soils. The fact that no killing takes place on the low moisture soil until after an exposure of 1 hour and 15 minutes and complete killing after 1 hour and 30 minutes is especially noteworthy.

Experiment No. 2.—Turkey Red on clay.—The plants were exposed to the low temperatures given in Table 2 for 15 minutes to 2 hours.

Table 1.—*The relation of soil moisture content to the resistance to cold of Turkey Red on quartz sand, expressed as percentage of plants killed.*

Length of exposure	Temperature, degrees C.	Percentage of plants killed on			
		20% moisture	30% moisture	40% moisture	50% moisture
15 minutes	—17.8	0	0	0	10
30 minutes	—18.3	0	30	0	13
45 minutes	—19.0	0	22	25	10
1 hr. 0 minutes	—19.0	0	0	10	80
1 hr. 15 minutes	—18.3	0	13	0	30
1 hr. 30 minutes	—17.8	100	30	50	70
1 hr. 45 minutes	—19.0	100	100	40	100
2 hrs. 0 minutes	—19.0	100	100	50	90
2 hrs. 15 minutes	—19.0	100	100	80	100
2 hrs. 30 minutes	—19.0	100	100	100	100

Table 2.—*The relation of soil moisture content to the resistance to cold of Turkey Red on clay, expressed as percentage of plants killed.*

Length of exposure	Temperature, degrees C.	Percentage of plants killed on			
		20% moisture	30% moisture	40% moisture	50% moisture
15 minutes	—19.0	0	0	10	30
30 minutes	—19.4	0	10	11	30
45 minutes	—19.0	10	30	50	30
1 hr. 0 minutes	—19.4	30	87	60	60
1 hr. 15 minutes	—20.0	100	70	78	60
1 hr. 30 minutes	—19.4	100	100	70	70
1 hr. 45 minutes	—20.0	100	100	80	100
2 hrs. 0 minutes	—20.6	100	100	100	100

The temperature was exceedingly low in this experiment; yet as in the previous lot there was no killing on the low moisture soils during the first part of the exposure, followed by a rapid increase in the rate of killing after the killing once set in. Killing on the high moisture soils began early but progressed less rapidly than in the case of the low moisture soils.

Experiment No. 3.—Mediterranean on brown silt loam.—The plants were exposed to the low temperatures given in Table 3 for 15 minutes to 1 hour and 30 minutes.

Table 3.—*The relation of soil moisture content to the resistance to cold of Mediterranean on brown silt loam, expressed as percentage of plants killed.*

Length of exposure	Temperature, degrees C.	Percentage of plants killed on			
		20% moisture	30% moisture	40% moisture	50% moisture
15 minutes	—16.7	20	30	40	40
30 minutes	—16.7	40	50	50	40
45 minutes	—18.3	70	70	70	60
1 hr. 0 minutes	—20.6	100	70	80	70
1 hr. 15 minutes	—19.4	100	100	90	80
1 hr. 30 minutes	—16.7	100	100	100	100

Here again, the low moisture soil shows less killing than the higher moisture soils during the early part of the exposure, but it is also the first to show complete killing. The uniformly high rate of killing of the plants in this experiment is accounted for by their greater age.

Experiment No. 4.—Mediterranean on clay.—The plants were exposed to the low temperatures given in Table 4 for 20 minutes to 2 hours and 40 minutes. The results given in Table 4 are based on a larger number of plants, 24 containers being used for each moisture content as compared with 6 to 8 in experiments previously cited.

TABLE 4.—*The relation of soil moisture content to the resistance to cold of Mediterranean on clay, expressed as percentage of plants killed.*

Length of exposure	Temperature, degrees C.	Percentage of plants killed on 20% moisture	30% moisture	40% moisture	50% moisture
20 minutes.......	—14.0	0	0	0	5
40 minutes.......	—14.0	4	6	10	8
1 hr. 0 minutes.......	—14.4	0	6	11	9
1 hr. 20 minutes.......	—14.4	0	54	32	25
1 hr. 40 minutes.......	—15.0	35	72	33	56
2 hrs. 0 minutes.......	—15.0	83	91	16	20
2 hrs. 20 minutes......	—15.0	100	100	80	46
2 hrs. 40 minutes......	—16.0	100	100	100	67

As in previous experiments, there is practically no injury on the low moisture soil during the first part of the exposure, followed by a rapid increase in the rate of killing. The influence of the high moisture content is well shown by the gradual increase in the rate of killing and the larger percentage of live plants toward the later part of the exposure.

Experiment No. 5—Marquis on brown silt loam.—The plants used in this experiment were grown the first part of May under conditions conducive to rapid growth, consequently they were very active when exposed to the low temperatures given in Table 5.

TABLE 5.—*The relation of soil moisture content to the resistance to cold of Marquis on brown silt loam, expressed as percentage of plants killed.*

Length of exposure	Temperature, degrees C.	Percentage of plants killed on 20% moisture	30% moisture	40% moisture	50% moisture
15 minutes.......	—15.0	0	5	26	14
30 minutes.......	—15.0	0	44	87	82
45 minutes.......	—15.0	11	45	96	83
1 hr. 0 minutes.......	—15.0	18	57	100	84
1 hr. 15 minutes.......	—15.0	33	52	80	90
1 hr. 30 minutes.......	—15.0	73	82	60	82
1 hr. 45 minutes.......	—15.0	90	96	100	93
2 hrs. 0 minutes.......	—15.0	100	100	95	97

Again, there is no killing on the low moisture soil during the first part of the exposure. The rapid increase in the rate of killing on the higher moisture soils is of special significance.

Experiment No. 6—Marquis on clay.—The plants used in this experiment were very young when exposed to the freezing temperatures six days after planting. This, as will be shown later, accounts for the low percentage of killing.

TABLE 6.—*The relation of soil moisture content to the resistance to cold of Marquis on clay, expressed as percentage of plants killed.*

Length of exposure	Temperature degrees C.	Percentage of plants killed on 20% moisture	30% moisture	40% moisture	50% moisture	100% moisture
10 minutes	—15.6	0	10	0	7	0
20 minutes	—15.6	0	12	7	0	0
30 minutes	—16.0	0	0	10	7	0
40 minutes	—16.0	0	10	15	10	0
50 minutes	—16.0	0	7	16	15	0
1 hr. 0 minutes	—16.0	0	20	20	25	8
1 hr. 10 minutes	—16.0	0	10	15	25	0
1 hr. 20 minutes	—16.0	0	10	20	25	15
1 hr. 30 minutes	—15.6	20	33	25	30	25
1 hr. 40 minutes	—16.0	45	25	15	20	10
1 hr. 50 minutes	—16.0	50	30	17	30	20
2 hrs. 0 minutes	—16.7	70	40	20	30	0

These results demonstrate the remarkable resistance of the plants on the low moisture soil. There was no killing up to 1 hour and 20 minutes; from there on, however, the rate of killing increased rapidly till in the end there was more killing on the low than on the high moisture soils. The behavior of the plants on the fully saturated soil was also significant. The soil was fully saturated after the plants came up.

RELATION OF AGE OF PLANTS TO RESISTANCE TO LOW TEMPERATURES

In connection with the first preliminary experiment it was noted that young plants were far more resistant to cold than old plants. An experiment was planned to demonstrate the extent to which the age of plants affected resistance. Table 7 shows the results obtained with plants from one to four weeks old, age being stated from time of planting. The plants were grown on a clay soil with 40% of moisture. The variety used was Turkey Red.

Even after an exposure of two hours with the temperature dropping down to —16.7°C., no damage resulted on the lot one week old, while all older plants were killed after an exposure of 30 minutes.

Another experiment with the age of the plants varying from six to ten days was conducted with the results given in Table 8.

TABLE 7.—*Effect of age of plants on resistance to low temperatures, expressed as percentage of plants killed.*

Length of exposure	Temperature, degrees C.	Percentage of plants killed 1 week old	2 weeks old	3 weeks old	4 weeks old
15 minutes	—15.6	0	40	20	100
30 minutes	—15.6	0	100	100	100

TABLE 8.—*Effect of age of plants on resistance to low temperatures, expressed as percentage of plants killed.*

Length of exposure	Temperature, degrees C.	Percentage of plants killed 6 days old	8 days old	10 days old
30 minutes	—16.7	0	0	0
1 hr. 0 minutes	—16.7	0	0	50
1 hr. 30 minutes	—16.7	0	20	60
2 hrs. 0 minutes	—16.7	0	100	100

These experiments show conclusively that wheat seedlings become more susceptible to low temperatures with advance in age.

DISCUSSION OF RESULTS

Concerning the relation of soil moisture content to cold resistance all experiments reported above show conclusively that a low percentage of moisture has a protective influence during the first part of the exposure. When killing on the low moisture soils once sets in, however, it progresses rapidly. This rapid rate of increase in the amount of killing is of special significance. All experiments show that a high percentage of soil moisture has a protective influence during the later part of the exposure. Plants on these soils were always the last to reach the point of complete killing.

The above findings can be explained by two main factors, *viz.*, (a) by the relative activity of the plants grown on soils with differing amounts of moisture, and (b) by the relation of the specific heat of water to that of soil particles.

It is well known that plants become less resistant to temperature extremes with an increase in their life or growing processes. The activities of plants are increased more and more as conditions for their optimum growth are approached. That more favorable growing conditions existed in the case of the higher soil moisture contents used in this investigation is brought out in Table 9. The figures are based on the dry weights of 12 plants.

Plants grown on the soil with 40% moisture were the most active. On the 50% moisture soil, due to lack of aeration resulting from the paraffin seal, a retarding influence on the growth of the plants may have been brought about by the production of toxic subtances. In

TABLE 9.—*The relation of soil moisture content to the rate of growth of plants, expressed as grams of dry matter produced by 12 plants.*

	Grams of dry matter in plants on soils with			
	20% moisture	30% moisture	40% moisture	50% moisture
Lot 1.........	0.157	0.259	0.303	0.273
Lot 2.........	0.164	0.249	0.266	0.251

referring to the data presented, it will be found that injury invariably begins on the 40 and 50% soils. In other words, the degree of injury during the early part of the exposure offers an index of the relative activity of the plants growing on the respective soil moistures.

The more active the plants the higher will be the percentage of killing from the very beginning of the exposure. This is especially the case on the high moisture soils. Experiment 5 illustrates this fact. The plants were grown at high temperatures and with intense sunlight previous to exposure to low temperatures.

A factor favoring the survival of the plants grown on the low moisture soil was their somewhat higher percentage of dry matter. It was observed throughout the course of the investigation that the leaves of the plants grown on the lower moisture soils were injured less for the first two periods of the exposure than the leaves of those grown on the higher moisture soils. After an exposure of 30 minutes, however, the leaves were killed back on all lots irrespective of soil moisture.

The explanation for the more or less gradual rate of increase in the percentage of killing on the high moisture soils is found in the relation of the specific heat of water to that of soil particles. The specific heat of water is 1.000 as compared with 0.193 for sand, 0.206 for clay, and 0.215 for loam. Consequently, the more water a soil contains the slower it will cool. This is shown in Table 10. This factor thus counterbalances the effects produced by the greater activity of the plants grown under more optimum conditions, that is, at higher moisture contents.

TABLE 10.—*The relation of soil moisture content to the rate of cooling when exposed to low temperatures.*

Length of exposure	Temperature, degrees C.	Temperature in degrees C. of soil with			
		20% moisture	30% moisture	40% moisture	50% moisture
15 minutes.......	—18.8	14	13	14	14
30 minutes.......	—18.3	6	6	8	7
45 minutes.......	—17.7	1	1	3	3
1 hr. 0 minutes	—17.7	0	0	1	1
1 hr. 15 minutes.......	—17.7	—1	—1	0	0
1 hr. 30 minutes.......	—17.7	—2.5	—2.5	0	0
1 hr. 45 minutes.......	—17.7	—5.0	—4.0	—1	0
2 hrs. 0 minutes.......	—17.7	—10.0	—8.0	—3	0

Concerning the practical application of the above findings, it must be kept in mind that under field conditions there are other factors beside soil moisture and soil temperature, chief among them being the phenomenon of heaving. It is a known fact that heaving, due to the great expansion of water upon freezing, is a greater source of damage on wet than on dry soils. A moist soil cools less rapidly than a dry soil; however, with a continuation of freezing temperatures the final temperature of a wet soil will ultimately be as low as, or under some conditions even lower than, that of a dry soil.

Thus, Salmon (3)[3] found the lowest soil temperatures in an extremely cold season on moist soils. He attributes this to the difference in the specific heat and the thermal conductivity of ice and water. The reduction in the specific heat of water upon freezing and the greater conductivity of ice as compared with that of water permits the temperature fluctuations of the air to be more quickly recorded in the soil. He states that "it appears probable that dry sand is colder during the winter than a wet sand regardless of the character of the season, but a dry clay or silt loam is colder than a wet soil of the same kind only when the ground remains unfrozen."

Sorauer (5) observed dry parts of fields to suffer more from frost than moist areas.

A high soil moisture content is of protective value in the case of rapidly fluctuating temperatures such as occur especially in early spring. Under such conditions it aids in keeping the soil temperature uniform and is instrumental in reducing damage to plants. This is well illustrated by the behavior of the plants on the soils containing 40 to 50% moisture.

The protective influence of a high soil moisture content is more prominent in nature than under the abnormal conditions under which the investigation had to be conducted. Due to the more unfavorable growing conditions in the field at the time when frost damage occurs as compared with greenhouse conditions, there is less variation in the activity of the plants grown on the different soil moistures. Also, the temperature changes are far more gradual in the field than those to which the plants were subjected in this investigation. There are never such rapid climatic changes as those to which the plants under test were exposed by taking them directly from the greenhouse into the refrigerator. Thus, with less variation in the activity of the plants and a more gradual cooling, which would give the plants an opportunity to adjust themselves to the new environment, there is every reason to believe that there is comparatively less killing on the higher soil moistures under field conditions than the results given in this paper indicate.

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[3] Reference by number is to "Literature Cited," p. 193.

The fact brought out that wheat seedlings become more susceptible to low temperatures as they grow older merits attention. Rein (2) states that young protoplasm has the inherent property to withstand lower temperatures than older cell contents. He found the younger scales of an onion to freeze at —6.36° C.,while the older scales froze at —6.22°C. Apelt (1) found a difference in the freezing points of the base, the middle portion, and the tip of potato sprouts, the parts freezing at —2.2°, —2.6°, and —3.2°C., respectively. Schaffnit (4) found that the tips of young growing sprouts of wheat showed a considerable degree of resistance to cold, owing presumably to the presence of bud scales and to the colloidal condition of certain cell contents. Winkler (6) found young leaves of coniferous trees more resistant to cold than old leaves.

This difference in the resistance to cold of young and old protoplasm may be due in part to advance in differentiation. The fact that older protoplasm is more susceptible to cold emphasizes the danger connected with allowing too rank a growth of wheat to take place in the autumn. The protective influence of blanketing the soil with a greater amount of plant material must be taken into consideration, however, and the producer should see to it that the growth of the plants is not too rank, yet that there be enough plant substance to offer some protection to the soil.

SUMMARY

Under extreme depressions of temperature, such as occurred in these investigations, low soil moisture, due to its retardation of the life processes of plants, exerts a protective influence during the first part of the exposure.

After killing once sets in on the low moisture soil it progresses rapidly.

Due to the greater activity of the plants grown on the higher moisture soils killing on them begins sooner but progresses less rapidly.

The more active the plants at the time of freezing the more marked is the protective influence of low soil moisture content during the early periods of exposure.

More plants survive on the high than on the low moisture soils. The plants on the soils containing 40 to 50 % moisture were always the last to reach the point of complete killing.

Wheat seedlings become more susceptible to low temperatures with advance in age.

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FACTORS INFLUENCING RESULTS FROM RATE- AND DATE-OF-SEEDING EXPERIMENTS WITH WHEAT IN THE WESTERN UNITED STATES[1]

John H. Martin[2]

INTRODUCTION

Experiments to determine the desirable rates and dates to sow wheat and other cereals have been conducted by nearly all agricultural experiment stations in this country. As a result of these experiments, and the experience of farmers, seeding practices are now fairly well standardized in most localities. Certain unreliable recommendations, however, have caused some farmers to sow at rates or on dates which will not produce the highest yields in normal or usual seasons. Seed of Stoner or Miracle wheat was widely sold some years ago as the result of claims that 1, 2, or 3 pecks per acre would produce as high or higher yields than thicker seedings, and that it would tiller and yield more than any other variety. Experiments with this wheat, which was merely the old Fulcaster variety under a new name, showed that it tillered no more than other soft red winter wheat varieties, and also that it yielded best when sown at 5 to 7 pecks per acre. Specific recommendations in regard to dates of seeding may lead one into an embarrassing predicament. The following information from a farm-

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[1] Contribution from the Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Read at the meeting of the Western Branch of the Society held at Fort Collins, Colo., June 18–20, 1925. Received for publication December 14, 1925.

[2] Associate Agronomist.

er in Illinois was attached to a report on wheat varieties received by the Office of Cereal Investigations, "the fool farm advisor named late in October for seeding and the late seeding all froze out, so you see the advisor is a liability and a millstone around the farmer's neck."

In the semiarid regions in the western half of the United States incorrect recommendations of the proper rates or dates of seeding have been frequent. This resulted from popular misconceptions concerning dry farming, limited or crude experiments, and the fact that many of the early experiments were conducted on virgin soils. Except at individual experiment stations little attempt has been made to analyze the factors controlling the results from these experiments in the Great Plains and Great Basin sections. At the meeting of the Western Branch of the American Society of Agronomy in 1924, Swanson[3] presented data on winter wheat which showed that the yields from the different dates of seeding were related to the mean temperature at seeding time and that the highest yields were obtained from wheat seeded when the mean daily temperature was about 65°F.

Thin seeding and early seeding have been advised usually for semiarid conditions. Many agronomists, including the writer, have advised seeding wheat at rates as low as 3 pecks per acre. Breithaupt (2),[4] Carleton (3), Cottrell (4), Farrell (5), Scudder (8), Widtsoe (10), and others have advised sowing wheat at less than 3 pecks per acre under certain conditions. Because of the greater tillering of early sown wheat, less seed has been assumed to be necessary than for later seeding and for this reason thick seeding of late sown wheat was recommended by Jardine (6), Atkinson (1), and others. It was largely to determine the soundness of certain of these recommendations that the results of the cooperative experiments conducted by the agricultural experiment stations of the several western states and the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture, were summarized.

EXPERIMENTAL METHODS

The numerous factors affecting the growth and development of a wheat plant between sowing and harvesting make the interpretations of yield results on the basis of the individual factors a difficult task. More intensive studies of these factors are needed. The accumulation of numerous data from several stations, however, has made possible the drawing of generalizations in regard to several factors influencing results from rate- and date-of-seeding experiments. The

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[3] Unpublished paper presented at the annual meeting of the Western Branch of the American Society of Agronomy, at Laramie, Wyo., July 21–23, 1924.

[4] Reference by number is to "Literature Cited," p. 225.

TABLE I.—*Location, altitude, precipitation, length of frost-free period, mean monthly autumn temperatures, and type of soil at 17 experiment stations in the western half of United States from which data are reported on rate- and date-of-seeding experiments with wheat.*

Location of station	Altitude, feet	Precipitation Normal or average, inches	Precipitation Length of record, years	Length of frost-free period, days	Mean temperature in degrees F. Aug.	Sept.	Oct.	Nov.	Type of soil
Great Plains area									
Amarillo, Tex	3,676	20.81	28	190	76	70	58	47	Chocolate clay loam
Lawton, Okla	1,111	30.87	47	209	82	74	62	50	Fine sandy loam
Hays, Kans	2,000	22.96	50	166	77	68	56	42	Silty clay loam
Akron, Colo	4,560	17.72	17	139	71	63	49	37	Sandy loam
Archer, Wyo	6,027	13.79	50	120	66	57	45	35	Medium sandy loam
Sheridan, Wyo	3,800	14.72	23	131	65	56	44	33	Dark clay loam
Newell, S. Dak	2,900	15.42	15	137	70	59	46	36	Clay (gumbo)
Highmore, S. Dak	1,890	16.75	26	137	71	63	48	32	Glacial clay loam
Brookings, S. Dak	1,636	19.99	30	127	68	60	46	30	Glacial sandy loam
Edgeley, N. Dak	1,468	17.57	20	129	66	54	46	30	Light sandy loam
Williston, N. Dak	1,875	15.07	40	119	66	57	43	27	Fine sandy loam
Moccasin, Mont	4,228	16.43	27	124	65	56	44	34	Dark clay loam
Great Basin area									
Nephi, Utah	6,000	13.27	22	106	70	61	47		Clay loam
Aberdeen, Idaho	4,400	9.15	13	101	67	56	45	34	Sandy clay loam
Burns, Ore	4,100	7.49	6	49	64	54	43	33	Silt loam to fine sandy loam
Moro, Ore	1,800	11.52	19	146	68	57	49	38	Silt loam
Lind, Wash	1,630	7.68	7	142	73	62	52	39	Fine sandy loam

data here discussed were obtained from 17 experiment stations in the Great Plains and Great Basin areas during the past 17 years. The location, altitude, precipitation, length of frost-free period, mean monthly autumn temperatures, and type of soil at each station are shown in Table 1. The data from the experiments were compiled from annual reports of the field stations on file in the Office of Cereal Investigations, except those from Edgeley, N. Dak., where only the early experiments were cooperative. The data from Edgeley were taken from N. Dak. Agr. Exp. Sta. Bul. 145. Many of the yields from individual stations which are presented here have been published, together with those from other cereal experiments at these stations. The experiments in most of the states were conducted in cooperation with the state agricultural experiment stations,[5] or the Office of Dry Land Agriculture of the Bureau of Plant Industry.

Unfortunately, the treatment, size, and age of the seed used were not stated in many of these reports. The treatment of seed with formaldehyde or copper sulfate causes swelling of the seed and slow or reduced germination. The results here summarized include both treated and untreated seed, so that rates of seeding showing the highest yields in some cases may be slightly higher than would be necessary for untreated seed. It also should be kept in mind that the seedbed usually is in better condition on the experimental plats than in ordinary farm practice where higher rates are advisable than are here indicated.

The border effect along the alleys between the plats might be a factor favoring thick-sown plats, but the usual absence of reduced yields from heavy rates of seeding indicates that border effect has little, if any, influence in rate-of-seeding experiments.

RATE-OF-SEEDING EXPERIMENTS

Results from both winter and spring wheats grown in rate-of-seeding experiments are discussed.

WINTER WHEAT

Yields from rate-of-seeding experiments with winter wheat are available from 10 stations in the Great Plains and 4 stations in the Great Basin area. These yields are given in Table 2, and the average yields are shown graphically in Fig. 1. Hard red winter varieties such as Turkey, Kharkof, or Kanred were sown in all of these experiments except at Nephi, Utah, where Kofod, a white wheat, also was grown to compare the results with those of Turkey. Considering the

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[5] The experiments at Lind, Washington, were cooperative until 1920. The data obtained since 1920 are included through the courtesy of the Washington Agricultural Experiment Station.

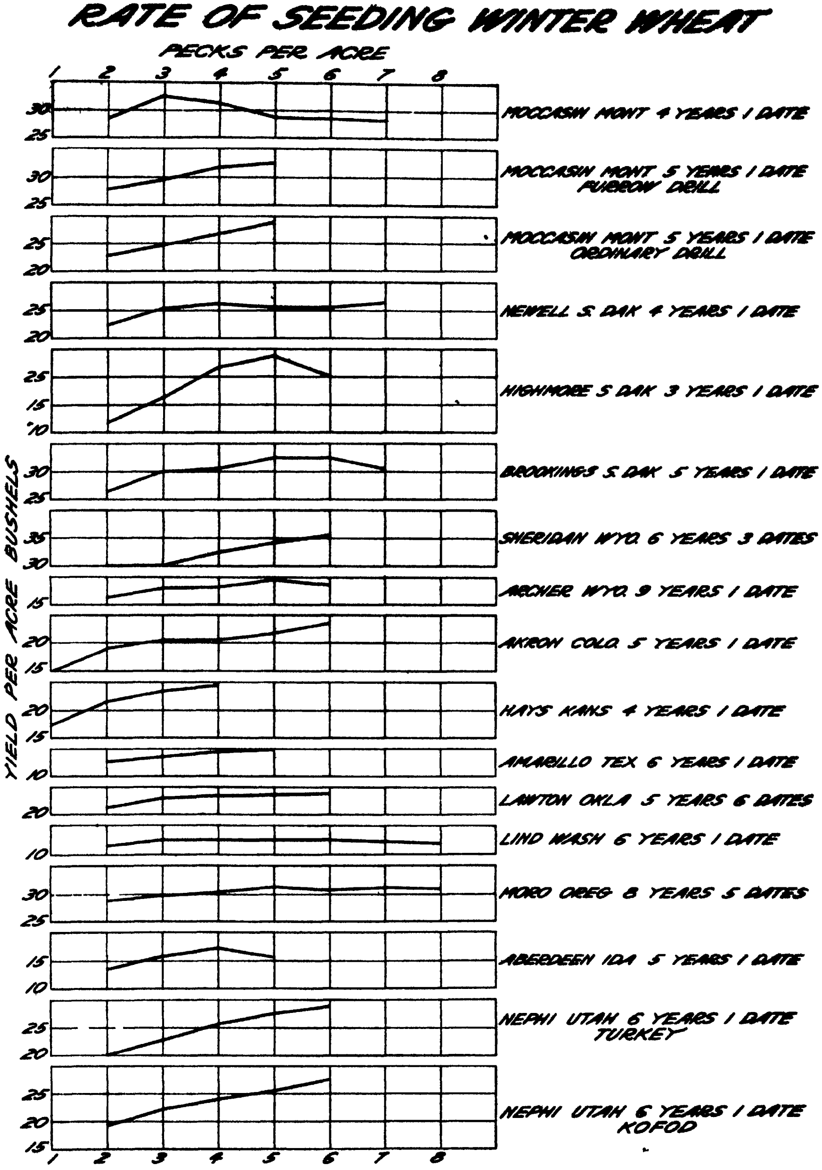

FIG. 1.—Average yields of winter wheat obtained from different rates of seeding.

uniformity in varietal types and cropping conditions, these data are about as extensive as it is possible to assemble for drawing generalizations. The average precipitation at these stations ranges from about

TABLE 2.—*Annual and average yields of winter wheat grown in rate-of-seeding experiments at 14 experiment stations during three or more years from 1910 to 1924, inclusive.*

Station and rate of seeding	Yield per acre (bushels)																
																Average	
	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	Gross	Net
Moccasin, Mont.																	
2 pecks........	36.5	33.3	16.7	27.7												28.6	28.1
3 pecks........	41.5	37.3	18.6	32.5												32.5	31.7
4 pecks........	38.0	35.0	21.7	30.3												31.3	30.3
5 pecks........	35.0	35.0	19.0	25.7												28.7	27.4
6 pecks........	31.6	35.3	20.4	26.7												28.5	27.0
7 pecks........	28.2	36.8	20.7	27.0												28.2	26.4
Moccasin, Mont. (Furrow drill)																	
2 pecks........											18.5	16.0	36.8	32.2	35.9	27.9	27.4
3 pecks........											19.3	19.4	38.0	33.7	37.7	29.6	28.8
4 pecks........											21.6	22.0	37.5	36.7	41.3	31.8	30.8
5 pecks........											22.3	22.5	37.8	37.6	42.4	32.5	31.2
Moccasin, Mont. (Ordinary drill)																	
2 pecks........											10.6	8.0	28.4	28.4	38.4	22.8	22.3
3 pecks........											13.4	9.2	31.6	30.3	39.0	24.7	23.9
4 pecks........											15.9	11.8	32.5	32.4	40.9	26.7	25.7
5 pecks........											18.0	13.5	34.4	35.7	41.7	28.7	27.4
Newell, S. Dak.																	
2 pecks........				26.4	23.0	36.7	3.1									22.3	21.8
3 pecks........				28.0	26.6	42.6	4.0									25.3	24.5
4 pecks........				27.3	24.9	48.3	4.6									26.3	25.3
5 pecks........				26.8	27.4	43.6	5.1									25.7	24.4
6 pecks........				27.4	24.6	45.8	5.4									25.8	24.3
7 pecks........				28.2	27.8	44.0	6.3									26.6	24.8

Highmore, S. Dak.														
2 pecks........				20.8	5.8		9.2						11.9	11.4
3 pecks........				23.0	14.2		11.5						16.2	15.4
4 pecks........				28.3	25.8		11.6						21.9	20.9
5 pecks........				32.2	28.0		11.3						23.8	22.5
6 pecks........				31.8	15.5		13.0						20.1	18.6
Brookings, S. Dak.														
2 pecks........	20.8	26.7	43.3			30.0	10.8						26.3	25.8
3 pecks........	26.5	28.3	42.5			40.0	12.5						30.0	29.2
4 pecks........	27.7	30.8	43.3			36.7	15.0						30.7	29.7
5 pecks........	30.0	30.8	40.0			44.2	18.0						32.6	31.3
6 pecks........	34.2	28.3	35.0			46.7	18.3						32.5	31.0
7 pecks........	32.7	28.3	27.5			48.3	16.6						30.7	28.9
Sheridan, Wyo.														
2 pecks........						55.4	7.2	36.5	22.3	35.0	23.2		29.9	29.4
3 pecks........						53.2	7.9	37.6	22.2	35.2	25.0		30.2	29.4
4 pecks........						54.8	8.8	40.4	23.1	39.9	27.7		32.5	31.5
5 pecks........						54.3	10.0	42.0	25.3	42.8	31.0		34.2	32.9
6 pecks........						54.7	9.9	43.0	28.8	43.4	33.1		35.5	34.0
8 pecks........						54.0	8.4	44.0	29.1	44.4	34.1		35.7	33.7
Archer, Wyo.														
2 pecks........			32.5		12.0	22.6	6.8	12.2	18.8		3.5	22.8	16.4	15.9
3 pecks........			35.5		12.7	25.1	6.3	14.0	22.9		4.0	23.7	18.0	17.2
4 pecks........			32.0		13.7	26.5	6.3	16.9	22.4		3.9	22.7	18.1	17.1
5 pecks........			34.8		13.4	32.6	5.3	15.3	25.1		5.2	24.9	19.6	18.3
6 pecks........			35.1		13.0	27.5	5.5	13.8	25.3		3.5	26.1	18.7	17.2
7 pecks........							4.0							
Akron, Colo.														
1 peck........	16.3	12.3	27.3	14.2	12.4	6.0							14.8	14.5
2 pecks........	18.3	18.3	30.4	24.8	10.2	12.6							19.1	18.6
3 pecks........	15.3	24.0	32.9	23.0	12.0	16.0							20.5	19.7
4 pecks........	16.3	24.3	32.4	22.5	11.0	17.4							20.7	19.7
5 pecks........	18.6	27.3	34.1	24.0	9.8	17.6							21.9	20.6
6 pecks........	18.6	27.3	34.4	30.6	15.7	15.1							23.6	22.1

TABLE 2.—*Continued.*

Station and rate of seeding	Yield per acre (bushels)																
																Average	
	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	Gross	Net
Hays, Kans.																	
1 peck											24.6	5.9	15.2		23.9	17.4	17.1
2 pecks											25.4	12.9	16.9		31.4	21.7	21.2
3 pecks											27.1	14.0	19.3		33.4	23.5	22.7
4 pecks											26.0	16.2	21.2		34.1	24.4	23.4
Amarillo, Texas																	
2 pecks				7.0	17.5	18.7	3.6	13.9		15.2						12.7	12.2
3 pecks				7.7	18.4	19.5	4.7	14.2		16.2						13.5	12.7
4 pecks				9.3	21.7	20.3	5.1	13.4		16.0						14.3	13.3
5 pecks				10.8	22.8	17.7	5.9	14.0		16.7						14.7	13.4
Lawton, Okla.																	
2 pecks										20.0	21.7	12.0		23.3	29.1	21.2	20.7
3 pecks										20.6	23.5	13.6		25.4	31.7	23.0	22.2
4 pecks										21.5	25.0	13.8		25.2	31.3	23.4	22.4
5 pecks										22.1	23.8	14.1		24.6	32.5	23.4	22.1
6 pecks										22.9	24.3	14.5		24.7	31.9	23.7	22.2
Lind, Wash.																	
2 pecks									7.7	14.7	7.0	13.0	5.0	22.6		11.7	11.2
3 pecks									7.3	16.8	9.3	12.1	4.2	26.7		12.7	11.9
4 pecks									7.0	15.8	10.5	12.2	5.7	25.7		12.8	11.8
5 pecks									7.0	16.0	10.5	12.0	5.5	25.3		12.7	11.4
6 pecks									6.8	18.3	10.8	11.0	4.9	25.1		12.8	11.3
7 pecks									6.7	14.7	11.5	12.1	5.7	23.5		12.4	10.6
8 pecks									6.0	15.7	10.1	11.5	5.4	24.5		12.2	10.2

Moro, Ore.														
2 pecks........				35.2	18.5	18.1	31.8	31.0	32.2	24.4	39.1		28.8	28.3
3 pecks........				32.2	20.1	19.9	33.2	34.2	35.1	25.8	39.3		29.9	29.1
4 pecks........				31.6	21.6	21.3	32.9	31.6	37.4	26.3	39.3		30.3	29.3
5 pecks........				35.0	23.2	21.4	37.1	33.8	36.1	26.8	37.1		31.3	30.0
6 pecks........				31.1	23.7	23.3	36.3	31.2	34.3	26.8	38.1		30.6	29.1
7 pecks........				31.5	22.7	25.6	37.3	33.9	35.2	27.7	37.0		31.4	29.6
8 pecks........				32.1	21.7	26.1	33.7	35.5	34.3	28.0	37.4		31.1	29.1
Aberdeen, Idaho														
2 pecks........	30.1	25.5	13.1	7.5		5.0							16.2	15.7
3 pecks........	29.8	34.0	16.5	9.3		4.7							18.9	18.1
4 pecks........	30.8	34.5	16.3	13.5		7.4							20.5	19.5
5 pecks........	34.1	26.8	10.6	14.5		7.3							18.7	17.4
6 pecks........			12.8	11.0		4.5								
Nephi, Utah (Turkey)														
2 pecks........		25.7	28.0	22.5	17.4		16.3	10.3					20.0	19.5
3 pecks........		32.8	30.8	20.2	19.6		18.1	15.8					22.9	22.1
4 pecks........		38.7	34.5	20.8	21.6		19.4	19.0					25.7	24.7
5 pecks........		44.2	37.3	22.1	22.3		21.5	19.2					27.8	26.5
6 pecks........		46.5	36.7	25.8	24.8		21.0	20.3					29.2	27.7
7 pecks........					26.3		23.5	19.0						
8 pecks........					28.3		22.5	19.2						
Nephi, Utah (Kofod)														
2 pecks........		32.5	26.0	13.7	17.1		12.5	13.4					19.2	18.7
3 pecks........		35.7	26.0	17.1	20.0		15.3	19.2					22.2	21.4
4 pecks........		39.7	30.0	17.1	20.1		17.0	20.1					24.0	23.0
5 pecks........		43.2	31.3	17.7	20.2		17.7	23.1					25.5	24.2
6 pecks........		46.3	33.3	22.4	21.8		17.1	22.6					27.3	25.8
7 pecks........					23.6		18.3	22.0						
8 pecks........					24.0		15.3	22.5						

8 inches at Lind, Wash., to 31 inches at Lawton, Okla. The altitudes for different stations vary between 1,100 and 6,000 feet and the soil types from sandy loams to heavy clays. In spite of these variations, the results obtained are similar at all stations.

The highest average gross yields were obtained from the 4-peck seedings at Hays, Kans., Lind, Wash., and Aberdeen, Idaho. At Hays, Kans., 4 pecks was the highest rate sown. The 5-peck seedings gave the highest gross yields at Highmore and Brookings, S. Dak., Archer, Wyo., Amarillo, Texas, and in the recent experiments at Moccasin, Mont. At Amarillo and at Moccasin in the recent experiments 5 pecks was the highest rate of seeding. Highest yields from the 6-peck seedings were obtained at Akron, Colo , Lawton, Okla., and Nephi, Utah; from the 7-peck seeding at Newell, S. Dak., and Moro, Ore ; and from the 8-peck seeding at Sheridan, Wyo. Deducting the quantity of seed sown, the highest net yields from the 4-peck seedings were obtained at Newell, S. Dak., Hays, Kans., Lawton, Okla., and Aberdeen, Ida.; from the 5-peck seeding at Highmore and Brookings, S. Dak., Archer, Wyo., Moccasin, Mont., Amarillo, Texas, and Moro, Ore.; and from the 6-peck seeding at Sheridan, Wyo., Akron, Colo., and Nephi, Utah. At no station was the rate of 2 pecks per acre sufficient for the highest average yields. In most experiments the yields from the 2-peck seedings have been decidedly less than from heavier seedings. The 3-peck seedings did not produce the highest average net yields at any station except Lind, Wash., and in the early experiments at Moccasin, Mont., where the crop was grown in single tenth-acre plats on new land. In the later replicated experiments at Moccasin the highest rate of seeding, 5 pecks per acre, gave the highest net yields. The seed sown at Lind was not treated with formaldehyde or copper sulfate except in the first season.

When all conditions are favorable, 2 or 3 pecks per acre may be sufficient seed, but usually thicker seeding is necessary for maximum yields. On farms where the seedbed usually is in poorer condition than in these experiments, it appears that in no case should the rate of seeding be less than 4 pecks per acre, while 5- or 6-peck seedings are likely to be more profitable, especially if the seed has been treated with formaldehyde or copper sulfate. An additional peck or two of seed is cheap insurance against thin stands, especially when it is realized that the thicker seeding will do no harm and may be very helpful if dry fall weather, winter killing, seed injury, or insect damage occur. The important point is to sow enough seed.

Effect of moisture.—The results show that thin seeding is of little or no value in preventing losses from drought. Thin seedings are just as likely to produce the highest yields in favorable moist seasons as in dry seasons. The writer has never observed a crop failure from thick seeding in dry seasons when thin seeding made a crop, while numerous fields which produced low yields because of thin stands have been seen. In the eastern half of the United States, under humid conditions, results tend to favor rates of seeding of 4 to 7 pecks, while in the experiments here cited the highest net yields were obtained from sowings of 3 to 6 pecks per acre. This slight difference may be the result of soil factors other than differences in moisture supply. There appears to be only a slight relation, if any, therefore, between the rainfall or moisture supply and the optimum rate of seeding wheat. This is shown both when results from stations having widely different annual precipitations and from the same station during wet and dry seasons are compiled.

Investigators as well as farmers frequently have been deceived by the small heads, short stems, and burned appearance of thickly sown wheat which actually yielded more per acre than the tall late plants with large heads resulting from thinly sown wheat.

Effect of winterkilling.—When partial winterkilling occurs or the stand is injured by soil blowing or insects, thick seeding tends to produce the highest yields. The thinner the wheat is sown the later will be the maturity, in general [Atkinson (1), Martin (7)]; and when hot winds, rust, etc., occur, the thicker seedings, because of earlier maturity, may escape injury better. At Moccasin, Mont., rate-of-seeding experiments were sown with both the furrow and ordinary drill. Winterkilling usually was greater in the wheat sown with the ordinary drill, and partly on this account the wheat sown at 3 pecks per acre with the furrow drill yielded more than that sown at 5 pecks per acre with the ordinary drill. In spite of this, the 5-peck seeding produced the highest gross and net yields with both methods of seeding.

Effect of variety.—It should be noted that all of these results were obtained with hard red winter wheats of the Crimean group which tiller readily. It might be assumed that other varieties which tiller less should be sown more thickly than the Crimean wheat. Rate-of-seeding experiments at Nephi, Utah, with both Turkey and Kofod wheats show that the yields from the different rates of seeding are closely parallel for the two varieties.

Effect of tillage and crop sequence.—At Hays, Kans., the rate- and date-of-seeding experiments were duplicated on fallow and on fall-plowed grain stubble. At Akron, Colo., the experiments were conducted on both fallow and corn ground. In spite of wide differences in yield between the two cropping methods at both stations the highest yields from each method were obtained from the same high rates of seeding. For this reason the data from the methods are not shown separately. Under conditions favoring a better stand for one soil treatment compared with another, higher rates of seeding for the poorer or drier seedbed might be necessary. At Archer, Wyo., a higher rate of seeding was necessary for oat stubble than for fallow.

SPRING WHEAT

Yields from rate-of-seeding experiments with spring wheat from nine stations in the Great Plains area and three stations in the Great Basin area are presented in Table 3 and graphically in Fig. 2. Both common and durum wheats were included in the experiments. Considering all varieties as a group, the highest average yields were obtained from the 4-peck seedings at Sheridan, Wyo., Akron, Colo., Archer, Wyo., and Lind, Wash. Common wheat at Highmore, S. Dak., gave the highest average yield from the 4-peck rate, although durum wheat at this station gave a maximum yield at the 5-peck rate. At Amarillo, Texas, the 3-peck and 4-peck seedings of common wheat produced the same average yields. The 5-peck seedings gave the highest average at Newell, S. Dak., and of durum wheat at Highmore, S. Dak., and Amarillo, Texas. For common wheat, the 6-peck seeding produced the highest yields at Williston, N. Dak.; the 7-peck seeding at Brookings, S Dak.; and the 8-peck seeding at Edgeley, N. Dak.; and of Pacific Bluestem at Moro, Ore; for durum wheat, the 9-peck rate gave the best yields at Edgeley, N. Dak. On the basis of net yields for common wheat the 3-peck seeding at Amarillo, Texas; the 4-peck seeding at Lind, Wash., and Highmore, S. Dak.; the 5-peck seeding of Pacific Bluestem at Moro, Ore.; the 6-peck seeding at Williston, N. Dak., and the 8-peck seeding at Edgeley, N. Dak., produced the most profitable yields. For durum wheat the best net yields were produced by the 3-peck seeding at Newell, S. Dak.; by the 4-peck seeding at Sheridan, Wyo., Akron, Colo., and Archer, Wyo.; by the 5-peck seeding at Highmore, S. Dak., and Amarillo, Texas; and by the 7-peck seeding at Edgeley, N. Dak., and Brookings, S. Dak. The results indicate a rather wide range of optimum rates of seeding for different stations with 4 to 7 pecks per acre appearing in general to be the most satisfactory. As with winter wheat, the important point is to secure a full stand. Thicker seedings than necessary do not appear to reduce yields in either wet or dry seasons, although the net yields usually are less. Thin seeding delays maturity and increases the hazard from rust, drought, and heat. In general, the best rate of seeding for spring wheat is about the same as for winter wheat in any locality.

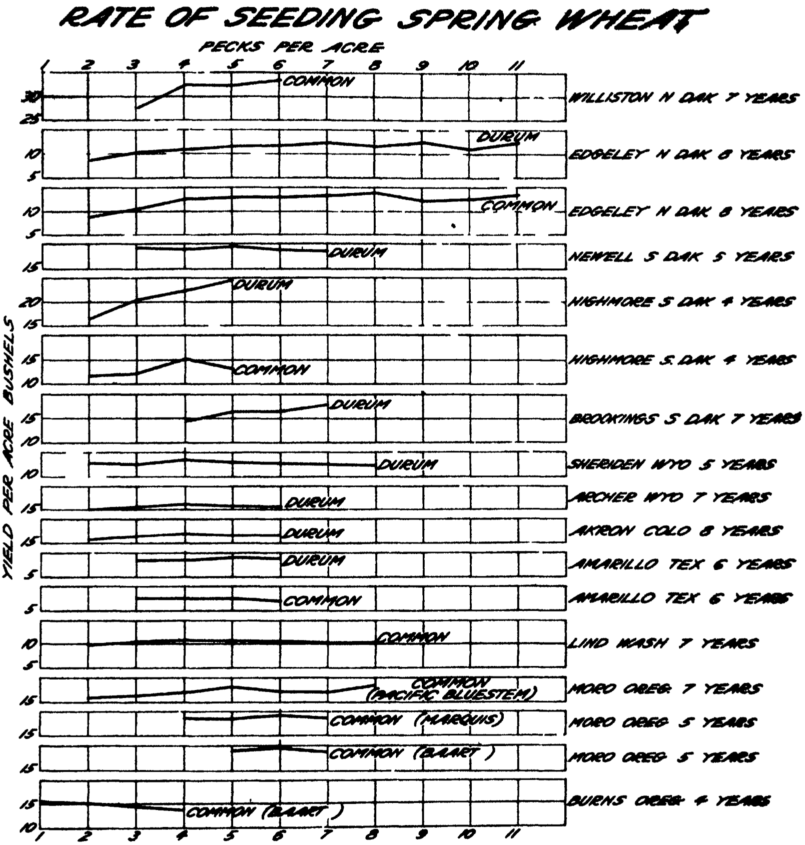

FIG. 2.—Average yields of spring wheat obtained from different rates of seeding.

Effect of moisture.—There appears to be only a slight relation between the moisture supply and the best rate of seeding In comparing wet and dry seasons at a single station the low rates of seeding are no better relatively in dry seasons than in wet seasons. In years of extreme drought all rates of seeding produced about the same yields. The results from the stations at which drought was a limiting factor in yield nearly every year, such as Newell, S. Dak., Sheridan, Wyo., Archer, Wyo., Amarillo, Texas, and Lind, Wash., favor seedings of not over 4 pecks per acre, although the results at Highmore, S. Dak., Edgeley, N. Dak., and Moro, Ore., where drought also was frequent, favor higher rates. Only at Burns, Ore., where conditions are too extreme for successful dry farming, do the results distinctly favor rates of seeding less than 4 pecks per acre. These *years from 1908 to 1923, inclusive.*

Station and and rate of seeding	Yield per acre (bushels)																	
	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	Average Gross	Average Net
Williston, N. Dak.[a] (common)																		
3 pecks. .				1.9	43.7	15.7	41.1	50.0	31.7	8.3							27.5	26.7
4 pecks. .				2.2	49.0	31.5	47.5	48.0	38.7	10.7							32.5	31.5
5 pecks. .				1.7	49.5	30.3	50.4	48.7	36.3	9.0							32.3	31.0
6 pecks. .				2.0	48.0	33.0	48.8	52.6	38.9	11.5							33.5	32.0
7 pecks. .				2.5	47.6	36.6												
8 pecks. .				2.0														
Edgeley, N. Dak.[b] (durum)																		
2 pecks. .	11.3	17.3	4.0		10.0	8.0	6.6		4.0								8.7	8.2
3 pecks. .	12.3	18.6	3.0		15.3	12.0	7.3		5.3								10.5	9.7
4 pecks. .	11.3	15.3	2.2		19.7	14.0	8.0		6.0								10.9	9.9
5 pecks. .	12.0	19.3	2.6		18.5	13.3	8.6		6.7								11.6	10.3
6 pecks. .	11.3	23.3	1.4		13.3	15.3	10.6		6.7								11.7	10.2
7 pecks. .	14.0	23.3	.8		16.6	15.3	9.6		6.7								12.3	10.5
8 pecks. .	12.0	22.0	.5		16.0	13.3	10.6		7.2								11.7	9.7
9 pecks. .	16.7	21.3	2.2		16.0	10.6	14.0		6.7								12.5	10.2
10 pecks. .	13.3	20.0	1.2		11.3	10.6	12.6		8.0								11.0	8.5
11 pecks. .	16.0	20.0	1.8		12.0	12.0	17.3		8.0								12.4	9.6
Edgeley, N. Dak.[c] (common)																		
2 pecks. .	10.0	16.6	3.1		14.0	11.3	3.3		4.0								8.9	8.4
3 pecks. .	8.7	22.6	4.4		14.6	12.2	3.6		6.0								10.3	9.5
4 pecks. .	12.7	22.6	6.1		19.3	14.6	4.3		6.7								12.3	11.3
5 pecks. .	13.3	22.6	6.1		20.0	14.0	6.6		8.0								12.9	11.6
6 pecks. .	13.3	22.0	6.4		26.0	12.0	5.0		6.7								13.1	11.6
7 pecks. .	13.3	22.0	5.8		23.3	14.0	8.0		8.0								13.5	11.7
8 pecks. .	15.3	21.3	4.2		26.0	14.0	5.6		10.0								13.8	11.8
9 pecks. .	12.7	20.0	3.3		23.3	15.3	10.0		10.7								13.6	11.3
10 pecks. .	13.3	19.3	3.4		22.0	15.3	6.6		9.3								12.7	10.2
11 pecks. .	12.7	19.3	3.1		23.3	16.0	10.4		10.0								13.5	10.7

(durum)										
3 pecks. .		9.3	2.2	61.6	11.2	12.4			19.3	18.5
4 pecks. .		9.8	2.0	60.1	10.7	12.4			19.0	18.0
5 pecks. .		10.4	2.3	61.4	11.2	11.6			19.4	18.1
6 pecks. .		9.9	2.0	59.2	10.9	12.3			18.9	17.4
7 pecks. .		10.3	2.0	57.4	11.5	12.4			18.7	16.9
8 pecks. .		10.6	1.9							
Highmore, S. Dak.[e]										
(durum)										
2 pecks. .	f	11.3	18.3	30.0	6.7				16.6	16.1
3 pecks. .	0	12.5	23.7	38.3	8.3	f	f		20.7	19.9
4 pecks. .	0	13.0	26.2	37.5	13.3	8.3	18.3		22.5	21.5
5 pecks. .	1.2	12.0	27.5	45.0	13.3	10.7	22.5		24.5	23.2
6 pecks. .	1.0					11.8	25.8			
7 pecks. .						11.0	25.0			
8 pecks. .						11.0	23.3			
Highmore, S. Dak.[g]										
(common)										
2 pecks. .	f	2.5	13.2	29.2	3.0				12.0	11.5
3 pecks. .	.5	3.5	13.5	27.5	5.0	f	f		12.4	11.6
4 pecks. .	.3	2.3	16.2	35.8	7.5	9.1	13.3		15.5	14.5
5 pecks. .	.5	.8	17.5	27.5	8.3	10.0	16.7		13.5	12.2
6 pecks. .	.7	1.7			10.0	12.9	15.0			
7 pecks. .						12.5	16.7			
8 pecks. .						13.7	10.8			
Brookings, S. Dak.[h]										
(durum)										
3 pecks. .		18.3	10.0							
4 pecks. .		25.0	17.5		9.2	18.3	24.2	6.6	16.8	15.8
5 pecks. .		25.0	19.2		11.7	19.3	29.2	10.0	19.1	17.8
6 pecks. .		23.0	20.0		13.3	21.1	28.3	9.0	19.1	17.6
7 pecks. .		26.6	20.0		13.3	19.3	35.0	10.8	20.8	19.0
8 pecks. .			21.7							

[a] Dakota 1913 to 1914; Power 1915 to 1917.

[b] Arnautka.

[c] Glyndon.

[e] Kubanka 1912 to 1915; Acme 1916 to 1918.

[f] Yields from these years not included in averages.

TABLE 3.—*Continued.*

Yield per acre (bushels)

Station and rate of seeding	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	Average Gross	Average Net
Sheridan, Wyo.[i] (durum)																		
2 pecks. .										6.9	17.2	0	11.6	1.9	29.1	22.9	12.8	12.3
3 pecks. .										6.7	17.5	0	13.1	2.4	24.4	23.8	12.6	11.8
4 pecks. .										5.8	19.1	0	15.3	2.7	28.0	22.9	13.4	12.4
5 pecks. .										4.9	19.2	0	16.0	2.9	23.6	24.7	13.0	11.7
6 pecks. .										4.9	17.5	0	16.2	2.6	26.5	22.0	12.8	11.3
7 pecks. .										4.7	16.8	0	18.0	2.6	24.4	20.0	12.4	10.6
Archer, Wyo.[j] (durum)																		
2 pecks. .						10.0	9.5	26.4	4.9	18.3	32.2	4.1					15.1	14.6
3 pecks. .						9.2	10.3	24.3	6.2	19.1	36.8	3.4					15.6	14.8
4 pecks. .						8.4	10.8	26.1	6.9	19.0	37.8	4.3					16.2	15.2
5 pecks. .						8.3	8.6	24.9	6.7	18.7	40.0	3.7					15.8	14.5
6 pecks. .						7.8	9.2	23.8	6.5	18.7	40.3	3.5					15.7	14.2
7 pecks. .						8.6	10.5	25.3	6.8	18.4	37.8							
Akron, Colo.[k] (durum)																		
1 peck . .							14.6							6.4	5.2			
2 pecks. .					41.0	7.3	18.0	30.0	8.0			8.3		7.1	4.8		15.6	15.1
3 pecks. .					37.3	8.6	19.6	29.5	9.8			12.2		7.4	6.2		16.3	15.5
4 pecks. .					37.0	10.9	20.0	29.5	11.0			11.9		7.5	7.7		16.9	15.9
5 pecks. .					30.3	11.6	22.0	29.5	11.2			10.6		8.4	7.6		16.4	15.1
6 pecks. .					28.3	11.1	21.3	30.2	12.2			10.0		10.2	8.6		16.5	15.0
7 pecks. .					27.0	11.6	21.0											
Amarillo, Texas[l] (durum)																		
3 pecks. .					11.2	4.3	13.7	12.7	5.0	4.0		[f]					8.5	7.7
4 pecks. .					10.7	3.5	15.5	14.3	3.9	3.9		23.3					8.6	7.6
5 pecks. .					11.2	4.3	16.7	14.3	4.2	3.8		23.3					9.1	7.8
6 pecks. .					11.2	3.5	16.7	15.2	4.2	3.4		24.4					9.0	7.5

Amarillo, Texas[m]														
(common)								*f*						
3 pecks. .	13.5	6.7	10.3	8.5	3.4	2.1		8.5					7.4	6.6
4 pecks. .	13.7	4.5	10.5	9.5	3.4	3.0		8.2					7.4	6.4
5 pecks. .	11.5	5.3	11.3	8.2	4.7	2.7		9.1					7.3	6.0
6 pecks. .	10.2	4.7	11.5	8.7	3.9	2.9							7.0	5.5
Lind, Wash.[n]														
(common)														
2 pecks. .						5.7	7.3	7.5	10.1	3.5	8.2	23.4	9.4	8.9
3 pecks. .						8.0	7.2	10.0	11.2	4.7	7.8	25.3	10.6	9.8
4 pecks. .						9.4	6.6	10.4	10.3	8.7	7.1	24.1	10.9	9.9
5 pecks. .						9.3	5.7	10.4	10.9	8.7	7.7	23.1	10.8	9.5
6 pecks. .						9.2	6.5	10.6	9.6	9.5	7.2	22.5	10.7	9.2
7 pecks. .						9.4	5.4	11.1	9.6	10.5	6.9	20.0	10.4	8.6
8 pecks. .						9.2	5.3	11.8	9.2	10.5	6.6	21.4	10.6	8.6
Moro, Ore.[o]														
(common)														
2 pecks. .	7.0	18.5	17.5	18.6	23.2	12.1	15.7						16.1	15.6
3 pecks. .	8.8	17.5	15.5	18.6	23.3	15.2	15.7						16.4	15.6
4 pecks. .	13.6	20.8	14.5	15.1	23.0	15.7	17.3						17.1	16.1
5 pecks. .	12.5	21.3	17.8	17.2	23.0	17.9	18.0						18.2	16.9
6 pecks. .	10.5	18.3	16.3	20.6	19.3	18.1	18.0						17.3	15.8
7 pecks. .	13.1	20.0	17.3	18.0	19.3	17.3	15.3						17.2	15.4
8 pecks. .	13.1	20.0	18.1	19.2	24.0	20.8	15.5						18.7	16.7
Moro, Ore.[p]														
(common)											*f*	*f*		
2 pecks. .						11.8					17.3	38.7		
3 pecks. .						13.3	16.7			20.8	20.3	38.7		
4 pecks. .						15.7	18.0	19.8		23.2	18.3	39.0		
5 pecks. .						14.7	18.7	21.2	19.2	22.1	18.7	37.0	19.2	17.9
6 pecks. .						15.7	19.3	22.0	18.5	23.5	17.3	34.7	19.8	18.3
7 pecks. .						15.2	18.0	22.5	17.6	21.6	18.7	32.7	19.0	17.2
8 pecks. .						16.3	19.7	21.5	18.0	24.0		28.7		

[i] Beloturka.

[j] Arnautka.

[k] Arnautka.

[m] Galgalos 1912; Fretes 1913 to 1919.

[n] Pacific Bluestem 1917; Baart 1918 to 1923.

[o] Pacific Bluestem.

TABLE 3.—*Concluded.*

Yield per acre (bushels)

Station and rate of seeding	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	Average Gross	Average Net
Moro, Ore.[q] (common)																		
2 pecks..										14.1					10.0			
3 pecks..										17.3	19.0			16.0	10.3			
4 pecks..										16.0	19.7	18.7	18.6	20.3	9.3		18.7	17.7
5 pecks..										18.7	19.3	18.9	16.5	19.7	9.3		18.6	17.3
6 pecks .										17.9	19.7	18.7	20.0	20.3			19.3	17.8
7 pecks..										21.6	16.0	20.0	17.8	18.0			18.7	16.9
8 pecks..											15.3	20.0		21.6				
Moro, Ore.[r] (common)																		
2 pecks..															26.0	40.3		
3 pecks..														29.3	26.0	40.3	31.9	31.1
4 pecks..													18.0	24.4	24.3	40.3	29.7	28.7
5 pecks..													19.4	26.7	19.7	39.7	28.7	27.4
6 pecks..													18.5	26.7	20.3	35.0	27.3	25.8
7 pecks..													19.0	30.9	18.7	30.3	26.6	24.8
8 pecks..														24.0		31.7		
Burns, Ore.[s] (common)																		
1 peck[t]..							17.0	22.0	8.2	14.7							15.5	15.2
2 pecks..							16.7	17.5	10.9	15.7							15.2	14.7
4 pecks..							16.5	13.7	10.2	15.1							13.9	12.9

[q] Marquis.

[r] Hard Federation.

[s] Pacific Bluestem 1914 to 1915; Baart 1916 to 1917.

[t] 20 pounds per acre.

data were obtained during only four years on rather un-uniform soil but also under low rainfall, so that probably thin seeding is advisable there. The highest average yields at Burns were obtained from seeding spring wheat at less than 2 pecks per acre.

Effect of variety.—In the Great Plains area durum wheat was sown in the rate-of-seeding experiments at Newell and Brookings, S. Dak., and Sheridan and Archer, Wyo.; common wheat at Williston, N. Dak.; while both durum and common wheats were grown in the experiments at Highmore, S. Dak., Edgeley, N. Dak., and Amarillo, Texas. At Newell 3 pecks, at Sheridan and Archer 4 pecks, and at Brookings 7 pecks per acre of durum wheat produced the highest net yields per acre, while at Williston 6 pecks per acre of common wheat produced the highest net yields. At Highmore, according to the data here given, the highest average net yields were obtained from the 5-peck seeding of durum wheat and the 4-peck seeding of common wheat. In more extended experiments the 4-peck seeding of common wheat outyielded the 5-peck seeding in only two out of seven years. More recent results at Highmore indicate that 5 or 6 pecks per acre are more favorable than lighter rates for both durum and common wheats. At Edgeley, N. Dak., the 7-peck seeding of durum wheat and the 8-peck seeding of common wheat produced the highest net yields. At Amarillo the 3-peck seeding of common wheat and the 5-peck seeding of durum wheat produced the highest net yields. The results on the whole indicate that durum and common wheat should be sown at about the same rate. There is very little justification for seeding common wheat at a lower rate than durum wheat in spite of past recommendations and the smaller kernels and greater tillering of the common wheat. Conversely, however, it appears advisable to sow durum wheat at least 1 peck per acre heavier than common wheat usually is sown, in order to insure a full stand. The larger heads and kernels of durum wheat seem to offset the fewer plants and tillers, but in any case sufficient seed should be sown to insure a stand that will utilize fully the soil area and permit uniform ripening.

Durum wheat was not sown in rate-of-seeding experiments in the Great Basin area, but at Moro, Ore., several varieties of common wheat have been included in the experiments. The yields up to 1918 slightly favor the 5-peck rate for Pacific Bluestem. From 1917 to 1923, 6 pecks per acre gave the best yield for Marquis and Baart. Marquis has smaller kernels and certainly tillers more than Baart and probably as much as Bluestem, yet it responds favorably to just as heavy seeding as either. In a recent three-year comparison of Baart and Hard Federation, the latter variety tillering very poorly and having smaller kernels, the highest net yields of both varieties were obtained from seeding 3 pecks per acre with progressive decreases in yield for heavier seedings. At both Moro and Lind in recent years seed wheat has been given dust treatments which do not swell or injure the seed and thus make thinner seeding possible. There was some indication at Moro, in 1923, that seeding of dust-treated wheat thicker than 6 pecks may be detrimental.

DATE-OF-SEEDING EXPERIMENTS

Results of experiments to determine the effect of dates of seeding on winter and spring wheat in both the Great Plains and Great Basin areas also are presented.

WINTER WHEAT

The hard red winter varieties, such as Turkey, Kharkof, Kanred, and Karmont, were sown in the date-of-seeding experiments with winter wheat. Results are available from nine stations in the Great Plains and two stations in the Great Basin. The date of seeding rather than the date of emergence of the seedings is here considered, because emergence is not controlled by the investigator. In reality, however, the date of emergence is the beginning of the growth period of the plant and is a better measure of the stage of development of the plant than the date of seeding. Many of the dates of seeding were not exactly as shown in the tables or figures but approximated those dates. Sowings were made at 15-day intervals about the first and middle of each month in nearly all experiments except at Hays, Kans., where sowings were made at weekly intervals. Yields obtained from sowings at different stations from August 1 to December 1 are presented in Table 4 and Fig. 3.

When sown in dry soil, seedings of two or three dates frequently have emerged simultaneously after a rain. Late seedings frequently did not emerge until spring. In spite of these discrepancies, average yields from several stations over a period of years give a fair indication of results to be expected from variation in date of seeding wheat. As far as the data here presented are concerned, the Hessian fly has not noticeably affected the wheat in these date-of-seeding experiments at any station.

The highest average yields were obtained from September 1 seedings at Moccasin, Mont., and Archer, Wyo.; from the September 15 seedings at Highmore, S. Dak., Akron, Colo., Lawton, Okla., Moro, Ore., and Aberdeen, Idaho; from the October 1 seedings at Newell, S. Dak., Sheridan, Wyo., and Hays, Kans.; and from the October 15

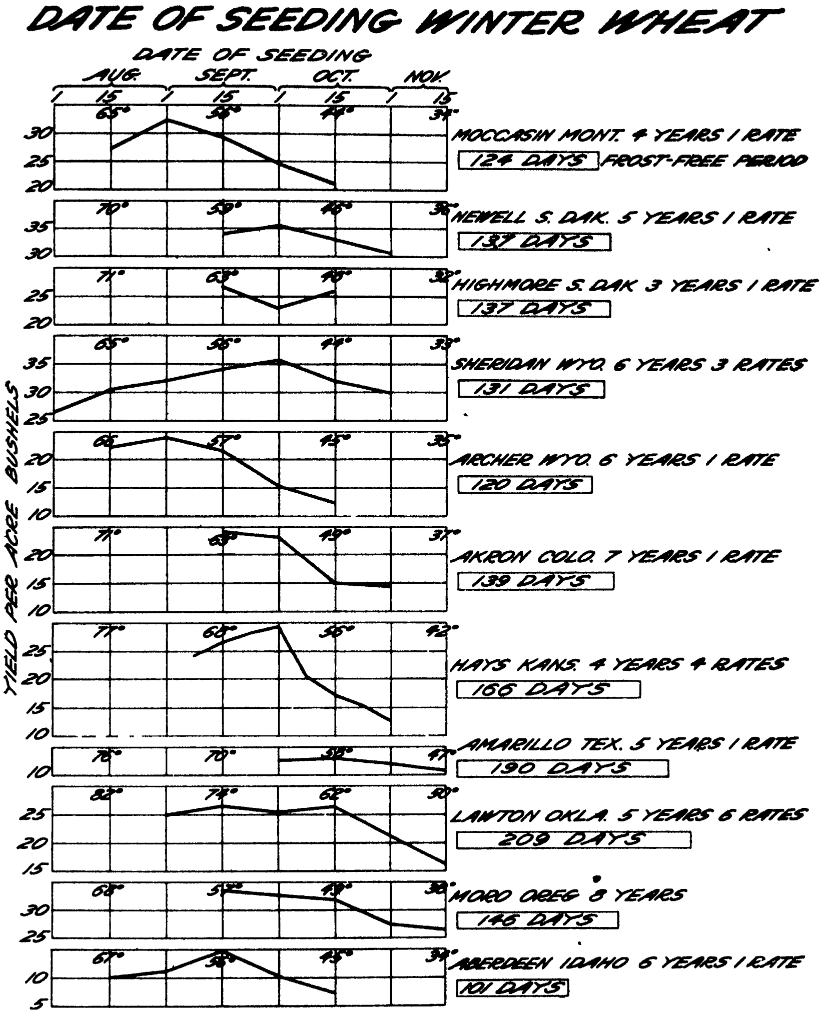

FIG. 3.—Average yields of winter wheat obtained from seeding on different dates.

seeding at Amarillo, Texas. These results indicate a range of about six weeks in the favorable dates of seeding throughout the Great Plains and Great Basin area, with medium dates giving the best results. There is some tendency favoring an earlier date of seeding for the northern stations when compared with the southern stations, altitude must be considered along with latitude, however, in determining ecological responses. Soil moisture supply and fall rains are so irregular and undependable that they can not be used as a basis for recommending dates of seeding, even though they probably

TABLE 4.—*Annual and average yields of winter wheat obtained in date-of-seeding experiments at 11 experiment stations in western United States during three or more years from 1908 to 1924, inclusive.*

Station and date of seeding	Yield per acre (bushels) 1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	Average
Moccasin, Mont.																		
Aug. 1				30.3		28.0												
Aug. 15				31.0	16.7	32.5	28.7											27.2
Sept. 1				35.6	20.0	46.0	28.7											32.6
Sept. 15				35.3	16.3	35.0	30.0											29.2
Oct. 1				30.0	17.5	26.8	23.3											24.4
Oct. 15				29.3	9.1	17.3	28.8											21.1
Newell, S. Dak.																		
Aug. 1						29.2												
Aug. 15		37.5				28.1												
Sept. 1	23.0	39.0				28.1												
Sept. 15	20.3	40.5				28.1	20.2	61.6										34.1
Oct. 1	24.3	43.0				28.1	21.1	60.9										35.5
Oct. 15	24.7	42.0				21.4	20.7	56.5										33.1
Nov. 1	25.5	37.3				16.3	19.1	55.2										30.7
Nov. 15						16.1		51.9										
Highmore, S. Dak.																		
Aug. 1											25.0							
Aug. 15																		
Sept. 1											15.8	24.5						
Sept. 15								34.2			16.2	29.6						26.7
Oct. 1								28.3			18.3	21.7						22.8
Oct. 15								25.8			34.3	17.5						25.9
Nov. 1								33.3				15.0						
Nov. 15								3.3				4.8						
Dec. 1								3.3										

Sheridan, Wyo.														
Aug 1							52.9	3.8	33.9	22.8	26.2	20.0		26.6
Aug 15							53.3	9.4	40.9	21.7	37.2	20.4		30.5
Sept. 1							55.3	9.6	43.2	24.0	33.8	26.8		32.1
Sept. 15							55.1	9.5	42.7	28.0	36.4	33.4		34.2
Oct. 1							57.2	9.8	47.9	25.8	44.1	29.6		35.7
Oct. 15							54.2	7.3	37.5	24.4	44.8	23.6		32.0
Nov. 1							46.8	5.0	30.6	8.8	50.6	7.4		24.9
Archer, Wyo.														
Aug. 15				29.6			26.3	5.9	14.5	29.0			28.5	22.3
Sept. 1				38.1			33.3	6.3	15.2	27.6			23.3	24.0
Sept. 15				38.8			30.8	7.7	5.8	22.7			25.0	21.8
Oct. 1				34.5			20.6	6.5	3.9	9.8			16.1	15.2
Oct. 15				25.6			16.7	3.1	4.1	7.9			16.2	12.3
Nov. 1							20.0	4.2	4.8	10.7			13.0	
Akron, Colo.														
Sept. 15	6.8	37.5	26.0	27.3	25.8	16.9	18.5							24.1
Oct. 1	5.5	32.7	26.6	34.3	22.2	13.2	17.6							23.2
Oct. 15	6.1	15.5	11.3	25.8	17.5	6.1	11.9							14.9
Nov. 1	6.6	13.3	13.6	26.6	21.6	0	10.8							14.6
Hays, Kans.														
Sept. 8									32.6	22.1	12.7		29.2	24.2
Sept. 15									32.5	24.4	13.3		35.6	26.5
Sept. 22									32.7	23.2	20.7		35.7	28.1
Sept. 29									29.9	26.3	21.5		39.1	29.2
Oct. 5									28.8	2.1	20.4		31.4	20.7
Oct. 12									23.1	0	17.8		27.6	17.1
Oct. 19									16.7	0	17.9		26.6	15.3
Oct. 26									10.0	0	21.0		20.6	12.9

TABLE 4.—*Concluded.*

Station and date of seeding	Yield per acre (bushels)																	
	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	Average
Amarillo, Texas																		
Oct. 1						5.1	21.9	16.7	8.2	11.6								12.7
Oct. 15						5.2	24.2	17.7	6.2	11.7								13.0
Nov. 1						6.4	21.6	14.4	6.2	11.5								12.0
Nov. 15						6.3	15.6	15.7	7.5	9.2								10.9
Lawton, Okla.																		
Sept. 1												22.5	22.0	15.7		29.7	34.5	24.9
Sept. 15												22.5	23.1	16.5		29.7	40.5	26.5
Oct. 1												22.7	26.1	14.5		27.2	36.8	25.5
Oct. 15												26.2	27.3	18.7		26.1	33.9	26.4
Nov. 1												23.5		13.3		19.3	25.7	
Nov. 15												20.0	19.9	8.5		15.7	16.9	16.2
Dec. 1												13.6						
Moro, Ore.																		
Aug. 15																36.3		
Sept. 1																34.6		
Sept. 15									29.9	31.1	20.8	34.5	44.3	39.9	29.7	34.2		33.1
Oct. 1									36.1	24.3	26.2	33.8	38.4	42.4	26.4	35.4		32.9
Oct. 15									35.3	20.1		38.9	26.8	38.2	27.5	40.3		32.4
Nov. 1									35.0		22.2	31.2	22.6	29.1	24.7	46.5		30.2
Nov. 15									25.8		20.3			25.0	24.4	42.9		27.7
Dec. 1										20.1								
Aberdeen, Idaho																		
Aug. 15						29.1	11.3	4.3	5.0	7.1	3.6							10.1
Sept. 1						25.3	16.6	8.1	6.6	5.0	4.6							11.0
Sept. 15						23.6	30.0	14.6	6.3	10.0	5.0							14.9
Oct. 1						16.0	22.0	3.6	8.1	7.3	5.1							10.4
Oct. 15						9.0	15.8	4.3	4.5	7.1	5.0							7.6

are the most important factors affecting the results from date-of-seeding experiments in the semiarid regions.

Effect of temperature.—A comparison of average yields with the average length of growing season in Fig. 3 shows that in general the longer the growing season the later the wheat can be sown with success Such differences in date of seeding, are not entirely proportional, however, to the differences in the length of growing seasons. In the eastern part of the United States, and to a less extent in the southern Great Plains area, wheat plants are not likely to survive to any extent unless the plants become well established in the fall with a good root system and numerous tillers. In the northern Great Plains, on the other hand, a good growth before the winter season is of no advantage and may be deterimental. .In the latter area, if the plants emerge and produce two or three leaves, they are likely to survive as well as, or better than, the well-developed plants from early seedings. Winter wheat plants usually are killed down to the crown in the northern Great Plains, so that the small plants have as good a start in the spring as the large ones. A heavy growth in the fall seems to exhaust available plant food and the soil moisture supply to no good purpose, and thus makes the conditions in the spring less favorable for recovery and reduces the supply of moisture for spring and summer growth. Extremely early seeding has not proved successful, principally because of the factors just mentioned. Very late seeding usually produces even poorer yields than early seeding because of poor development and late maturity. If the wheat plants barely emerge in the fall, they are likely to be killed in the winter. Frequently, the latest seedings do not emerge until spring and thus mature so late that the crop may be injured by drought, hot winds, or rust. Wheat which does not emerge until spring usually yields less than wheat which emerges in the fall, although after very severe winters it sometimes escapes winterkilling and may eventually yield more than wheat which emerged in the fall and was partly winterkilled. Sometimes the seeds germinate and many of the plants emerge but develop so poorly that they do not survive the winter.

At most stations, as reference to Tables 1 and 4 will show, the optimum date of seeding occurs when the mean daily temperature lies between 50° and 62°F., but at the most favorable seeding time higher temperatures prevail in the South than in the North.

SPRING WHEAT

Experiments with dates of seeding of spring wheat at six stations in the Great Plains and two stations in the Great Basin are reported. The yields are shown in Table 5 and graphically in Fig. 4. Owing to

TABLE 5 —*Annual and average yields of spring wheat grown in a date-of-seeding experiment at eight experiment stations during three or more years from 1912 to 1923, inclusive*

Station and date of seeding	Yield per acre (bushels)												
	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	Average
Williston, N Dak [a]													
May 1			43 0	52 3	32 4	9 8							34 4
May 15			41 6	43 0	24 5	9 8							29 7
June 1			32 5	33 7	14 4	0							20 2
Newell S Dak [b]													
April 15	0			52 5	14 2								22 2
May 1	0			37 2	12 3								16 5
May 15	13 5			27 3	4 9								15 2
Highmore, S Dak [c] (durum)													
March 1							8 3						
March 15			23 3		32 5		20 8						
April 1		2 0	25 8	56 7	28 3	[d]23 3	10 8	21 6					24 2
April 15		2 0	24 3	40 0	25 0		8 3	21 7					20 2
May 1		1 0	13 8	25 0	18 3	[d]15 0	10 8	15 8					14 1
May 15		3	1 2			[d]5 8	10 0	7 1					
Highmore, S Dak [e] (common)													
March 1							15 0						
March 15					21 7		16 8						
April 1					13 3	19 1	16 8	13 1					15 6
April 15					13 3		15 8	12 1					
May 1					3 0	17 5	14 1	6 5					10 3
May 15						8 7	9 2	3 1					
Sheridan, Wyo [f] (durum)													
April 1							17 0	0	16 5	6 0	20 0	21 3	13 5
April 15							17 9	0	17 8	5 3	20 7	22 7	14 1
May 1							16 7	0	11 3	0	14 4	14 7	9 5
May 15							12 8	0	9 6	0	8 9	0	5 2
June 1							2 7	0	0	0	0	0	5
June 15							0	0	0	0	0	0	0

Archer, Wyo.[g]													
April 1			8.3										
April 15		16.7	8.3	15.8	4.5	17.8	d	2.7					11.0
May 1		9.3	8.6	16.5	4.7	17.6	29.8	3.7					10.1
May 15		9.0	6.3	12.8	1.2	18.2	27.1	.5					8.0
June 1							13.7	.5					
June 15							5.4						
Amarillo, Texas[h] (durum)													
March 1			11.8		4.2	3.8		23.3					
March 15		5.7	10.0	7.3	4.2	2.2		21.1					5.9
April 1	[d]10.7	4.8	7.0	6.3	4.7	2.0							5.0
April 15	[d]11.0	4.2	5.7	0									
Amarillo, Texas[f] (common)													
March 1			10.3		3.4	3.6		8.2					6.4
March 15		4.5	6.2	9.5	3.9	1.6		5.6					5.2
April 1	14.8	4.5	3.3	5.0	3.4	.9							
April 15	8.7	4.2	1.5	0									
Lind, Wash.[j] (common)													
Early (March 25)						9.4	6.6	10.4	10.3	8.7	6.3	22.9	10.7
Medium (April 15)						5.1	5.3	10.0	9.9	8.2	5.6	21.5	9.4
Late (May 6)						2.6	3.3	8.0	8.6	4.6	5.0	17.9	7.1
Moro, Ore.[k] (common)													
Early (March 26)	11.2	19.5	16.7	18.2	22.1	16.7	16.5						17.3
Late (April 23)	13.6	9.7	7.7	10.9	19.7	13.1	11.6						12.3

[a] Dakota 1914; Power 1915 to 1917.

[b] Kubanka.

[c] Kubanka.

[d] Yields from these years not included in averages.

[e] Marquis.

[f] Beloturka.

[g] Ladoga.

[h] Marouani.

[i] Fretes.

[j] Baart

[k] Pacific Bluestem.

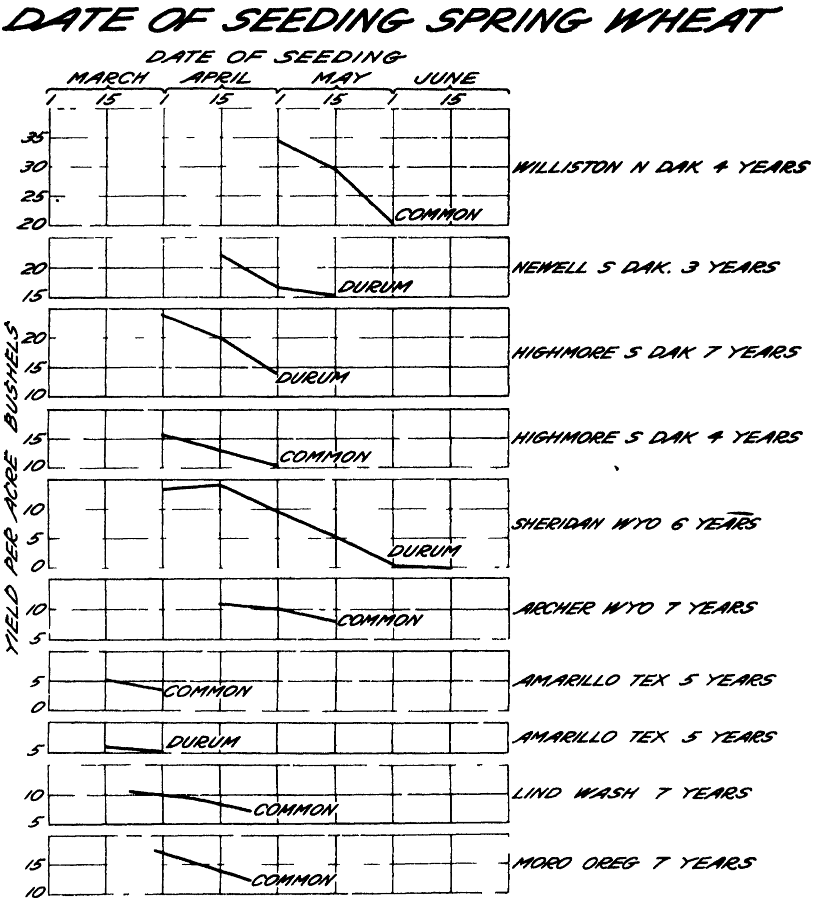

FIG. 4.—Average yields of spring wheat obtained from seeding on different dates.

the very definite practical benefits of early seeding, most of these experiments have not been very extensive. Irregularity in the opening of the spring season and the variations of rainy weather and wet soil in the spring usually prevented seeding on regular dates in any series of seasons. The first date in the spring when it is practicable to sow has varied widely from season to season. In general, the earlier the seeding for any given season the higher was the yield in these experiments. The earliest date of sowing produced the highest average yields at all stations except that at Sheridan, Wyo., where the April 15 seeding out-yielded the April 1 seeding by 0.6 bushel per acre. The necessity of early seeding of spring wheat is generally understood by farmers as well as investigators. The more favorable the season the more important it is to sow early. The occasional season in which late seeding has been satisfactory probably has caused some farmers to become careless in regard to the time of sowing. Without doubt, early sowing is the most important factor in spring wheat production. On the other hand, extremely early seeding is of no advantage when the plants do not emerge earlier than those of somewhat later seedings. Neither is such early seeding injurious to the crop except in very rare cases where greatly delayed germination may result in the rotting of seed, so that the usual recommendation to sow as early as the land can be put into condition is a safe one.

Effect of variety.—In the date-of-seeding experiments here discussed three varieties of durum wheat and seven varieties of common wheat were grown. All varieties produced the highest yields from the earliest seedings, except the Beloturka (Kubanka) wheat at Sheridan, which yielded more from the second seeding. Although each variety produced the maximum yield from early seeding, some varieties apparently were less affected by later seeding than others. Experiments are now in progress to determine this point.

COMBINED RATE- AND DATE-OF-SEEDING EXPERIMENTS

Combined rate- and date-of-seeding experiments with hard red winter wheat were conducted at Sheridan, Wyo , Akron, Colo., Hays, Kans , Lawton, Okla., and Moro, Ore. In addition, a rate-of-seeding test with spring wheat on two dates of seeding about a month apart was conducted at Moro, Ore. The yields from most of the rates and dates of seeding considered separately have been shown previously, but the combined data are shown in Table 6 and Fig. 5. The outstanding result of the combined experiments is that rates and dates of seeding are practically independent. Thin seeding has produced the lowest average yields at all stations. The rates of seeding show similar trends for all dates, but there is a somewhat wider spread in yield from the different rates of seeding in the early sown wheat than in the late-sown wheat. This indicates that thick seeding is even more important for early seeding than for late seeding under the conditions of these experiments. It is a well-known fact that early sown wheat tillers more than late-sown wheat, but these results indicate that it is safer to sow thickly than to depend upon tillering to produce a full stand. The results at Manhattan, Kans., presented by Jardine (6) in 1915 indicate the desirability of using different rates of seeding for early and late seedings of wheat, also. Recent experiments at Manhattan show only a slight advantage for different rates and dates of seeding which are practicable. Late seedings at Manhattan are so

TABLE 6.—*Average yields of wheat obtained in combination rate- and date-of-seeding experiments at five stations in western United States during four to eight years.*

Station and date of seeding	Yield per acre (bushels) Rate of seeding (pecks per acre) 1	2	3	4	5	6	7	8	Average
Sheridan, Wyo.[a]									
August 1				25.8		30.1			
August 15		29.4	29.4	34.6	37.6	39.6		38.8	34.9
September 1			31.2	35.9		36.7			
September 15		35.5	36.7	37.9	39.6	40.5		40.3	38.4
October 1			36.0	37.3		39.1			
October 15		31.6	32.2	35.4	35.8	35.6		37.0	34.6
November 1			26.6	26.7		28.9			
Average				33.4		35.8			
Akron, Colo.[b]									
August 15	8.2	11.0	13.7	15.3	16.9				13.0
September 1	13.9	16.3	17.2	18.5	19.2				17.0
September 15	15.8	16.1	16.5	16.0	15.4				16.0
October 1	8.0	8.7	9.9	10.1	10.5				9.4
October 15	8.2	9.4	10.4	11.3	12.4				10.3
Average	10.8	12.3	13.5	14.2	14.9				
Hays, Kans.[c]									
September 8	17.8	23.0	27.9	27.9					24.2
September 15	21.9	26.2	27.9	29.8					26.5
September 22	22.4	27.2	30.6	32.2					28.1
September 29	23.7	31.1	30.9	31.0					29.2
October 6	18.1	22.1	19.8	22.6					20.7
October 13	14.1	16.0	19.1	19.2					17.1
October 20	11.8	15.2	17.4	16.9					15.3
October 26	9.6	12.6	14.1	15.3					12.0
Average	17.4	21.7	23.5	24.4					
Lawton, Okla[d]									
September 1		19.4	20.4	20.1	21.5	22.0			20.7
September 15		22.2	23.3	23.1	21.7	21.5			22.4
October 1		19.2	21.3	22.0	22.6	22.4			21.5
October 15		20.8	22.6	23.0	22.7	23.6			22.5
November 1		14.8	16.4	16.3	17.1	17.4			16.4
November 15		11.6	13.3	14.3	14.0	14.3			13.5
Average		18.0	19.6	19.8	19.9	20.2			
Moro, Ore.[e]									
September 15		30.2	33.8	32.8	33.9	33.4	35.1	34.4	33.4
October 1		33.5	33.0	32.4	35.1	31.9	32.2	31.1	32.7
October 15		31.5	32.0	32.1	31.1	31.4	31.2	33.0	31.8
November 1		24.4	25.3	27.1	28.3	28.3	29.2	29.0	27.4
November 15		24.3	24.4	27.0	27.5	27.5	27.8	26.9	26.5
Average		28.8	29.7	30.3	31.2	30.5	31.1	30.9	
Moro, Ore.[f] (spring wheat)									
Early (March 26)		16.1	16.4	17.1	18.2	17.3	17.2	18.7	17.3
Late (April 23)		12.2	13.0	12.3	12.2	12.0	12.1	12.1	12.3

[a] Av for 7 yrs, 1918-1924, inclusive.
[b] Av for 5 yrs, 1920-1924, inclusive.
[c] Av for 4 yrs, 1920-1922 and 1924.
[d] Av for 6 yrs, 1918-1921 and 1923-1924.
[e] Av for 8 yrs, 1916-1923, inclusive.
[f] Av for 7 yrs, 1912-1918, inclusive.

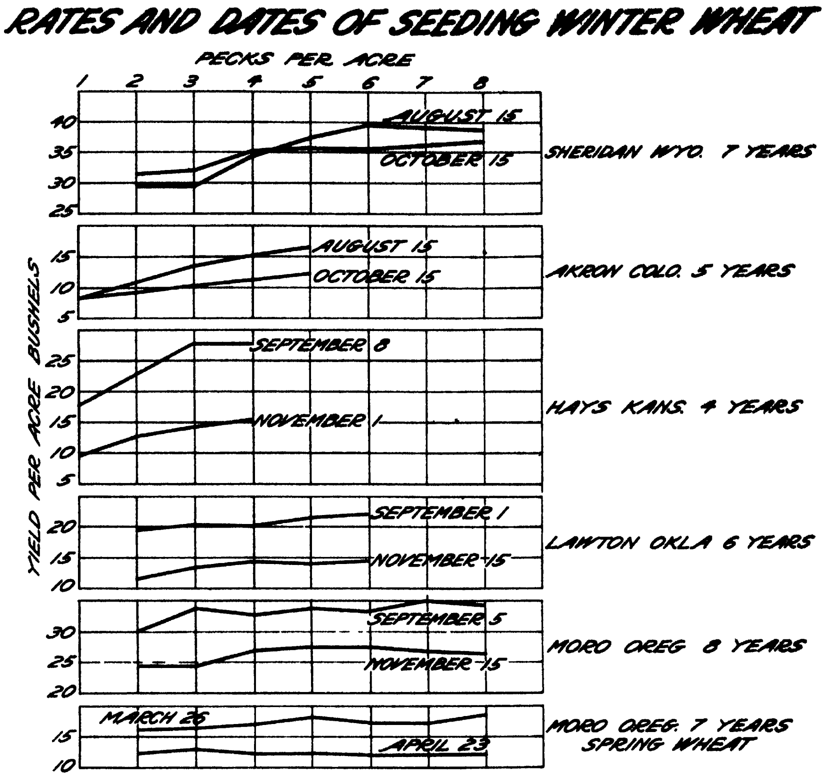

FIG. 5.—Average yields of winter wheat obtained from seeding on different dates and at different rates.

severely winterkilled that a satisfactory spring stand can not be obtained except by very thick seeding.

The data here presented are of interest for the negative results obtained, and they show that there probably is little necessity for longer continuing combination rate- and date-of-seeding experiments in the Great Plains and Great Basin areas.

DISCUSSION

In considering results from rate-of-seeding experiments the numerous opportunities for the wheat plant to adjust itself should be kept in mind. If the seedbed is too dry emergence is poor and a thick stand is prevented. If the plants are overcrowded the weak ones are eliminated. Tillering, the number of heads which emerge from the sheaths, the length of heads, the number of fertile spikelets and florets, and the development and size of the kernels all depend upon suitable environmental and nutritional factors during each stage of growth.

The average test weight per bushel is about the same for light and heavy seeding and in some dry seasons the heavier seeding may produce the heavier kernels. It is thus easy to understand why the optimum rates of seeding cover a rather wide range and why these optimum rates show so little relation to annual precipitation, tillage methods, variety, and date of seeding.

After wheat has emerged with good stands, or passed through the winter with good stands when fall sown, the subsequent results obtained are largely determined by the relation of the stage of growth of the plant to the conditions with regard to moisture, nutrients, temperature, and light. The relative extent to which these factors affect the tillering, jointing, heading, and ripening are not know. The beginnings of these growth stages doubtless are manifestations of metabolic processes rather than direct effects of the environmental factors.

It is well known that the differences in dates of heading and maturity are less than the differences in dates of sowing [Atkinson (1) and Stephens, et al. (9)], except when certain seedings fail to emerge promptly or when sowing is very late in the spring. Dates of heading and ripening are affected not only by environment but also by the age of the plants or tillers and the thickness of stand [Atkinson (1) and Martin (7)]. Conditions favoring growth often are not favorable for seed development.

The chief advantages of early seeding are the longer growth period, which permits maximum development, and the earlier maturity, which often allows the plants partly to escape injury from drought, heat, hot winds, and diseases which become more severe as summer advances. The abnormally early occurrence of any of these destructive factors often prevents the escape from injury and eliminates the advantage of early seeding. It is chiefly the irregularities in moisture, temperature, and diseases which cause the diversity in results of date-of-seeding experiments with wheat. In general, winter wheat should be sown at a time which will permit the proper amount of fall growth, depending upon the locality, so as to permit it to make the best possible start in the spring. Extreme dates are to be avoided. Spring wheat usually should be sown early so as to avoid injury from drought, heat, and diseases which are more likely to occur as the season advances. Temperature changes and rainfall throughout the season will affect in a different manner or degree the wheat seeded on the various dates.

A late rain following an extended drought may be of no benefit to early sown wheat which is beyond recovery, while late-sown wheat in some cases may be at a stage to make the best use of the moisture.

Whether or not to "seed in the dust" in the fall is a question for the individual farmer to answer. In the Great Plains area, where fall rains are expected, this usually is a safe practice; but in the Great Basin it is somewhat doubtful, especially in localities where spring wheat yields nearly as well as winter wheat.

SUMMARY

The optimum rate of seeding for wheat is practically independent of soil type, moisture, locality, date of seeding, cultural treatment, and variety. The optimum date of seeding for winter wheat is independent of soil type, annual precipitation, variety, and rate of seeding, but is related somewhat to temperature, even though the same temperature conditions do not apply in all sections. Rates of 4 to 6 pecks per acre in general have produced the highest net yields of winter and spring wheat. Early seeding of spring wheat and medium seeding of winter wheat usually are most favorable.

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COMPOSITION OF GRASS FROM WOODLAND AND FROM OPEN PASTURE[1]

F. A. WELTON AND V. H. MORRIS[2]

When the first pioneer came to Ohio, most of the 41,000 square miles of the state was in timber, and, according to estimates of foresters, there must have been at that time no less than 175,000,000,000 board feet of standing timber. Today, it is estimated that the total of all standing timber left is less than 9,000,000,000 board feet and that cutting and devastation are continuing at the rate of 210,000,000 board feet annually. This process has transformed Ohio from a wood-exporting to a wood-importing state; the consumption now exceeding the output by more than 1,200,000,000 board feet annually. The timber remaining occupies not more than 3,500,000 acres. Very little of this acreage is in a state of natural forest. Aside from a few parks, most of it is in isolated tracts, chiefly farm woods. To care properly for these farm woods is one of the important and difficult problems in the conservation of the remaining timber in the state.

OBJECT

From the standpoint of the preservation and production of timber in farm woods, foresters recommend that the pasturing of them be discouraged and, if possible, avoided altogether. They contend that pasturing results in injury through defoliation, cropping of bark and stems, and by uprooting and killing many seedlings. Furthermore, they say, the trampling of the animals exposes, more or less, the roots of the larger trees and tends to pack the ground, thus making difficult the starting of seedling trees.

Farmers are reluctant to discontinue the pasturing of woods. They feel they cannot sacrifice the pasturage and this feeling is accentuated by the steady decline in the productivity of their permanent pastures, which is becoming more and more pronounced with the passing of the years. Among stockmen the feeling is general that livestock do not relish woodland pasture as well as they do open pasture, but there is little or no experimental evidence in support of this view.

The purpose of this paper is to consider open and woodland pastures with respect to their relative yield and quality, particularly the latter. As used in this paper, woodland pasture refers to that grown among trees; open pasture to that grown on cleared land.

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This work was undertaken at the instance of Edmund Secrest, State Forester of Ohio, and to him the writers are indebted for many helpful suggestions.

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MATERIAL AND METHODS

The material used in this paper consists of unshaded and shaded pasture, chiefly native bluegrass. The two classes of grass were grown under three different situations, *viz.*, (a) old pasture unfertilized (one series of samples in and one outside the woods); (b) new pasture unfertilized (one series of samples in and one outside the woods); and (c) old pasture liberally fertilized with manure. In the last case the shade was provided artificially, a part being furnished by cheesecloth and a part by the use of lath frames. In making the lath frames, a space equal to the width of the lath was left between each pair of laths. The frames, therefore, furnished approximately 50% shade.

The first situation was the only one of the three which represents typical woodland pasture conditions. The other two were designed to supplement various phases of the first. In this pasture the stand of grass in the woods was such that the surface of the ground presented a solid green appearance in the spring. The location of the trees was such that complete shading existed at no time but a partial shade prevailed all the time.

In the second situation, the shade was more intense than in the first. In fact it was so dense that all the native grass had died, and it was this barrenness of the ground that made a new seeding possible. Very little if any direct sunlight ever reached this area. The new seedings, in and outside of the woods, were made the preceding fall, September 10, 1923. Both areas were sown from the same stock of bluegrass seed. The seeding in the woods lasted but one season, probably on account of the density of the shade.

The third situation was established in order to overcome any possible effect that the growing trees might have on the composition of the grass. The artificial shades were placed in an old pasture field which had been liberally manured a few years previous. This grass made a very luxuriant growth.

In all these tests cuttings for yield and samples for chemical analysis were taken at irregular intervals during the summer of 1924. The height of the grass varied somewhat at each cutting, but in no case was it allowed to come into head before clipping.

ENVIRONMENTAL CONDITIONS OF GROWTH

Before presenting any results it is perhaps desirable to make the differences in conditions of growth more specific than is implied by the words unshaded and shaded.

An attempt was made to measure the differences in environmental conditions between the unshaded and shaded pasture with respect to light, temperature, and rate of evaporation.

LIGHT

For measuring differences in light, use was made of the chemical photometer described by Ridgeway (7)[3], the action of which depends on the decomposition of a solution of oxalic acid under the influence of uranium acetate; the decomposition being dependent on and proportional to the amount of light.

The date and duration of the exposure of the photometer in the old and the new pastures and in the artificially shaded pasture are shown in Table 1.

TABLE 1.—*Light in unshaded and shaded pasture.*

	Old pasture		New pasture			Old pasture		
Date	Open	Woods	Open	Woods	Date	Open	Lath	Cheesecloth
	%	%	%	%		%	%	%
Aug. 2 to 4	100	9.91	100	4.74				
Aug. 22 to 26	100	15.20	100	5.88	Aug. 22 to 26	100	48.55	48.23
Sept. 8 to 12	100	23.24	100	14.29	Sept. 8 to 12	100	87.85	83.17
Oct. 3 to 8	100	19.83	100	11.62	Oct. 8 to 11	100	50.00	50.00

In Table 1 the percentages refer to the amount of oxalic acid decomposed under the influence of the light that struck the unshaded and shaded plats. During each period of exposure the amount decomposed in the open pasture was recorded as 100%. Using this amount as a basis, the proportionate amount decomposed in the shade was computed and recorded also in percentage. For example, during the period of August 2 to 4 the amount of oxalic acid decomposed in light in the open was 1.75 grams, while in the woods it was 0.173 gram. Since the amount of light in the open represented by the decomposed oxalic acid is recorded as 100%, then that in the woods may be expressed by $\frac{0.173}{1.750}$ or 9.91%. The percentages in the table are, therefore, to be regarded as a measure not of the absolute but of the relative amount of light in the unshaded and shaded situations.

From Table 1 it may be noted that there was a marked reduction in light in the woods as compared with the open. As might be expected, the amount of the reduction was greater in the new than in the old seeding because the barrenness of the ground in the woods where the new seeding was made was due presumably to the density of shade which had prevailed there in previous years. As artificial shades, the lath frame and cheesecloth were about equally effective.

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[3] Reference by number is to "Literature Cited," p. 237.

TEMPERATURE

Beginning August 23 and ending October 3, the maximum and minimum temperatures were recorded in the unshaded and shaded plats in both old and new pastures. The thermometers in the open were so arranged that they were not exposed directly to the sunlight. The readings in both old and new pastures are shown in Table 2.

TABLE 2.—*Temperature under different conditions of growth.*

	Maximum				Minimum			
	Old pasture		New pasture		Old pasture		New pasture	
Date	Open	Woods	Open	Woods	Open	Woods	Open	Woods
Average of 36 days, Aug. 23 to Oct. 3...	80.69	71.53	78.25	70.72	45.75	50.00	47.67	49.83

From the figures in Table 2 it is clear that, as compared with the temperature in the woods, temperature in the open not only rises higher in the day time but drops lower in the night, thus making a greater degree of variability in the open than in the woods.

EVAPORATION

The rate of evaporation of moisture from the soil in the unshaded and shaded plats was measured by means of black spherical atmometers mounted according to the Shive (9) plan. The difference in the rate of evaporation between the unshaded and shaded situations is recorded in Table 3.

TABLE 3.—*Rate of evaporation in unshaded and shaded pasture.*

	Old pasture		New pasture			Old pasture		
Date	Open	Woods	Open	Woods	Date	Open	Lath	Cheese-cloth
	cc.	cc.	cc.	cc.		cc.	cc.	cc.
July 1 to Aug. 2	630	359	596	402				
Aug. 2 to Aug. 22	426	300	580	312				
Aug. 22 to Sept. 11	407	290	561	295	Aug. 20 to Sept. 4	469	266	207
Sept. 11 to Oct. 8	374	355	484	322	Sept. 5 to Oct. 8	641	327	270
Oct. 8 to Oct. 21	247	166	331	200	Oct. 8 to Oct. 21	243	124	114
Total 113 days	2,084	1,470	2,552	1,531	Total 63 days	1,353	717	591

From Table 3 it will be noted that the rate of evaporation was in all cases less in the shade than in the open. In the woods, however, the amount of moisture conserved by the shade of the trees was no doubt more than offset by the water requirements of the trees, so that there was less moisture available for the growing grass in the woods than in the open. On the contrary, in the artificially shaded pasture, all the moisture conserved was available to the grass and this, no doubt, was one factor which contributed to the greater growth of grass in the artificial shade than in the open; a fact to which reference will be made later.

From the foregoing, it appears that, aside from a marked difference in light between the unshaded and shaded situations, there was also a contrast in temperature and a considerable difference in the rate of evaporation.

Having considered briefly some of the more important differences in environment under which the different classes of grass were grown, we now pass to a consideration of the effect, if any, of these differences in environmental conditions on the yield and composition of the grass produced.

RESULTS AND DISCUSSION

YIELD

In the woods the yield of grass varies widely, the amount of growth ranging all the way from nothing on the one hand to a fairly luxuriant growth on the other. The yields recorded from the plats in this experiment are, therefore, in no sense to be regarded as standard, or as a general average. They merely represent the amount of growth obtained under the one specific set of conditions which obtained in this experiment.

In Table 4 are given the green and dry weights and percentages of moisture in grass grown on the plats in the woods and in the open.

TABLE 4.—*Yield of grass in pounds per acre in the open and in the woods.*

Date of cutting	Green weight		Dry weight		Percentage of moisture	
	Open	Woods	Open	Woods	Open	Woods
May 21	1,012.7	510.8	262.4	130.2	74.09	74.53
June 10	430.6	201.4	126.3	54.0	70.66	73.12
June 30	1,308.3	492.7	374.3	96.3	71.40	80.47
Aug. 1	1,119.6	240.5	363.7	67.4	67.53	71.96
Total	3,871.2	1,445.4	1,126.7	347.9	70.92[a]	75.02[a]

[a] Average.

The yields are calculated from the average production of three square-rod plats. The yield of dry matter produced in the woods was 69.2% less than the amount produced in the open. Moreover, the quantity of weeds was greater at each cutting in the woods than in the open. The weeds varied with the season, the kinds found at different periods being similar to the ordinary succession of a typical beech-maple climax forest. On the last date, August 1, the proportion of weeds in each sample was determined. Assuming that the percentages of weeds in the samples taken on this date represent the average quantities found in the previous samples, the total yield of actual bluegrass has been calculated. The results, recorded in Table 5, show that the amount of bluegrass produced in the woods was 85.6% less than that produced in the open.

TABLE 5.—*Yield of bluegrass in pounds per acre in the open and in the woods.*

Sample	Total yield dry matter	Weeds, %	Total yield of bluegrass
Open............	1,126.7	40	676.0
Woods..........	347.9	72	97.4

The poor showing of the woodland pasture is not due to an exceptionally high yield of the open pasture with which it was compared. In fact the yield of the open pasture in question was relatively low. This is indicated by comparing its yield with the yields of the heavily manured pasture, under unshaded and shaded conditions, as recorded in Table 6.

TABLE 6.—*Yield in pounds per acre of unshaded and shaded grass, well manured.*

	Green weight			Dry weight			Percentage of moisture		
Date	Open	Lath[a]	Cheese-cloth	Open	Lath[a]	Cheese-cloth	Open	Lath	Cheese-cloth
June 5	2,091	1,332	2,535	455	233	467	78.23	82.51	81.57
June 30	7,157	6,153	8,913	1,667	1,119	1,569	76.71	81.81	82.39
Aug. 6	7,477	6,161	7,138	2,030	1,348	1,540	72.84	78.12	78.42
Total	16,726	13,647	18,587	4,153	2,700	3,577	75.93[b]	80.81[b]	80.79[b]

[a] Relatively low yields due to burrowing of moles in the ground.

[b] Average.

These yields are regarded as indicative only because they were calculated from the growth obtained on very small areas, 64 square feet. The reason for presenting them at all is that they serve to indicate that the yield of grass in the open as compared with that of the woodland pasture was not excessively high and hence the comparison is not exaggerated to the detriment of the woodland pasture.

Incidentally, it may be noted that the percentage of moisture in the more luxuriant well-manured pasture grass was approximately 5% higher than that grown in the old unmanured pasture. Moreover, in all the shaded samples, the percentage of moisture was about 5% higher than in the corresponding unshaded samples. This fact would seem to indicate that the shaded grass remains succulent for a longer period than the unshaded.

COMPOSITION

Chemical analyses following the standard procedure adopted by the Association of Official Agricultural Chemists were made on dry samples preserved from each cutting. The results are shown in Table 7.

TABLE 7.—*Composition of bluegrass in old pasture.*

Kind of sample	Pounds of dry matter in 100 pounds fresh grass	Pounds in 100 pounds of dry substance Ash	Crude protein	Carbohydrates	Fat
		May 22			
Open..... ..	25.91	5.87	11.77	77.15	5.21
Woodland..	25.47	8.16	11.78	75.02	5.02
		June 10			
Open......	29.34	8.07	14.42	72.02	5.49
Woodland..	26.88	9.75	16.93	68.63	4.69
		July 2			
Open......	28.60	7.66	15.17	71.64	5.87
Woodland..	19.53	10.54	15.62	70.62	5.53
		August 4			
Open......	32.47	7.39	14.99	74.59	6.10
Woodland..	28.04	10.41	13.80	71.79	3.99
		September 16			
Open......	33.28	6.76	16.74	72.57	3.94
Woodland..	22.83	9.46	21.68	64.78	4.07
		October 30			
Open.. ..	36.63	7.10	13.98	75.29	3.63
Woodland..	27.92	9.10	19.84	67.80	3.25

In taking these samples great care was exercised in an effort to exclude all foreign grasses. It is not claimed that the separation was complete in every instance. That the contamination, if any, was not material, however, is indicated by the results shown in Table 8.

TABLE 8.—*Composition of bluegrass in new pasture.*

Kind of sample	Pounds of dry matter in 100 pounds fresh grass	Pounds in 100 pounds of dry substance Ash	Crude protein	Carbohydrates	Fat
Open......	30.53	7.93	10.25	76.84	4.98
Woodland..	23.51	13.14	20.25	60.87	5.74

These analyses were made on samples grown from the new seedings made in September, 1923. The differences in composition between the open and woodland samples are similar to those recorded in Table 7. The difference in carbohydrates and protein, however, is more marked. This is perhaps due to the greater density of the shade.

Similar results were obtained on grass shaded artificially. The composition of samples of grass grown in the open, under laths, and under cheesecloth is shown in Table 9.

TABLE 9.—*Composition of bluegrass in old pasture with artificial shade.*

Kind of sample	Pounds of dry matter in 100 pounds fresh grass	Ash	Crude protein	Carbohydrates	Fat
		Pounds in 100 pounds of dry substance			
		June 5			
Open......	21.77	11.53	22.78	60.40	5.28
Lath......	17.49	13.72	22.98	57.97	5.32
Cheesecloth	18.43	13.51	22.95	57.95	5.59
		June 30			
Open......	23.29	10.09	18.33	64.58	7.00
Lath......	18.19	13.74	19.79	60.75	5.72
Cheesecloth	17.61	11.75	19.93	62.58	5.73
		August 6			
Open......	27.16	9.46	18.08	65.97	6.48
Lath......	21.88	10.37	19.56	64.08	5.99
Cheesecloth	21.58	11.31	21.27	60.10	7.32
		September 12			
Open......	27.31	9.15	19.40	67.41	4.02
Lath	20.58	10.49	23.52	61.27	4.71
Cheesecloth	17.03	10.98	23.25	60.83	4.93
		October 14			
Open......	22.15	10.56	24.37	60.27	4.78
Lath ...	18.70	11.39	26.04	57.75	5.44
Cheesecloth	16.54	13.66	26.06	55.19	5.07
		November 20			
Open......	34.08	8.80	19.24	67.90	4.05
Lath	26.16	10.97	24.50	59.56	4.97
Cheesecloth	21.94	11.30	23.92	59.34	5.42

From Tables 7, 8, and 9 it may be noted that in each of the three series of samples there is a consistent difference in total dry matter, carbohydrates, ash, and, with one exception, crude protein, the shaded samples running lower in dry matter and carbohydrates and higher in percentage of ash and protein. Although the percentage of protein is higher, the difference in dry matter is such that the total amount, on the average of all the series, is less in the shaded than in the unshaded grass. The total amounts of ash in the two classes of grass are not materially different. The relatively high percentage in the shaded grass results apparently from the relatively low content of dry matter. That shaded grass should contain less carbohydrates than unshaded grass is to be expected because the formation of these compounds depends on the action of chlorophyll in the presence of light.

Even though the carbohydrate content of the unshaded grass is higher than that of the shaded, the work of Harcourt (3) and of Salmon, Swanson, and McCampbell (8) with alfalfa and of Waters (10) with timothy indicates that an increase in the dry matter content of any given forage is not necessarily accompanied by an increase in digestible nutrients. In the work of these investigators the increase in dry matter is related to the age of the forage. With the approach of full maturity there is usually a marked development of crude fiber or indigestible constituents. In the grass experiments under consideration, however, the clipping of the shaded and unshaded grass was always made on the same day, thus eliminating any variations which might possibly result from differences in age. In this case, therefore, it is probable that the increase in dry matter meant an increase in digestible nutrients.

Using the figures for digestibility of bluegrass given by Henry and Morrison (4) and calculating the total digestible nutrients of the open and shaded pasture, basing computations on the average composition of all the clippings, it was found that the shaded pasture contained 22% less total nutrients than the unshaded in the old pasture; 27% less in the new pasture; and 25% less in the artificially shaded pasture. The finding of a reduction of nutrients in the shaded pasture agrees with the results obtained by Moreillon (6).

Feeding values based on analyses made on air-dry material, however, are not necessarily an accurate measure of the relative feeding values of the same material in a green state. Brown and Morris (1) found that in the slow process of air drying metabolic changes continue for some time and these result in a marked reduction in starch and sugars. In order to inhibit enzymatic and respiratory processes, Link and Tottingham (5) first heated their material in an autoclave; while Davis, Daish, and Sawyer (2) and others preserved their green material in alcohol raised to the boiling point for a short period. Plant chemists who have focussed their attention on methods of sampling have in recent years quite generally followed the practice of preserving their material in alcohol.

In these experiments, in addition to the air-dried samples, a duplicate series of samples of fresh grass was preserved in alcohol. This was done in order to determine the character of the carbohydrates, particularly the sugars, as they exist in the green grass.

The results obtained from the old, the new, and the artificially shaded pastures are shown in Tables 10, 11, and 12, respectively.

From Tables 10, 11, and 12 it may be noted that the shaded grass contained less free-reducing sugars, less inverted sugars, and less easily hydrolyzable carbohydrates. The amount of the difference based on the average of all the determinations was 31.84%, 48.80%, and 34.58%, respectively, in the old pasture; 55.30%, 68.85%, and 52.80%, respectively, in the new pasture; and 36.82%, 49.91%, and 37.88%, respectivey, in the artificially shaded pasture. It will be noted that the greatest differences were in the inverted sugars.

TABLE 10.—*Carbohydrates in grass from old pasture.*

Pounds in 100 pounds of fresh sample

Kind of sample	Dry weight	Reducing sugars[a]	Inverted sugars[a]	Easily hydrolyzable carbohydrates[a]
May 1				
Open......	25.91	0.99	3.02	4.63
Woodland..	25.47	0.71	2.54	3.98
May 21				
Open......	29.34	0.90	2.58	6.60
Woodland..	26.88	0.78	2.00	5.38
June 30				
Open......	28.60	0.61	2.35	5.68
Woodland..	19.53	0.32	0.26	3.28
August 1				
Open......	32.47	1.92	2.24	6.91
Woodland..	28.04	0.51	1.23	5.44
September 17				
Open......	33.28	0.76	2.27	9.14
Woodland..	22.83	0.60	0.80	4.57
October 30				
Open......	36.63	1.31	3.75	7.49
Woodland..	27.92	0.89	1.47	3.81

[a] Results calculated and expressed as dextrose.

TABLE 11.—*Carbohydrates in grass from new pasture.*

Pounds in 100 pounds of fresh sample

Kind of sample	Dry weight	Reducing sugars[a]	Inverted sugars[a]	Easily hydrolyzable carbohydrates[a]
June 30				
Open	31.19	0.68	1.39	7.26
Woodland..	18.30	0.30	0.39	2.79
August 1				
Open......	30.53	0.64	2.15	5.94
Woodland..	23.51	0.29	0.70	3.44

[a] Results calculated and expressed as dextrose.

From the standpoint of palatability, these differences may be significant, because it is permissible to assume that the grass with the higher sugar content would be eaten with the greater relish. At least some kinds of livestock prefer sweet feeds. Dairymen, anxious to make high records, have found that they can induce a greater consumption of roughage by pouring syrup on it.

Of course it is understood that many things enter into the palatability of any green feed. Not only are the composition and aroma important, but there must be considered also such things as the taste and habits of the animals. These figures, however, indicate that there may be some basis in fact for the claim that woodland pasture is less palatable than is that grown in the open.

In this connection it is of interest to recall that livestock usually

TABLE 12.—*Carbohydrates in grass from old pasture artificially shaded.*

Kind of sample	Dry weight	Pounds in 100 pounds of fresh sample Reducing sugars[a]	Inverted sugars[a]	Easily hydrolyzable carbohydrates[a]
		June 5		
Open......	21.77	0.87	2.15	2.94
Lath......	17.49	0.54	0.91	2.30
Cheesecloth	18.43	0.65	2.08	2.25
		June 30		
Open......	23.29	0.65	1.79	4.14
Lath......	18.19	0.44	0.73	2.89
Cheesecloth	17.61	0.36	0.51	2.69
		August 6		
Open......	27.16	0.61	2.41	4.70
Lath......	21.88	0.35	0.99	3.25
Cheesecloth	21.58	0.32	1.07	2.98
		September 12		
Open......	27.31	0.74	2.10	5.38
Lath......	20.58	0.45	0.89	3.31
Cheesecloth	17.03	0.46	0.87	2.57
		October 14		
Open......	22.15	0.84	3.22	3.49
Lath.....	18.70	0.57	1.18	2.74
Cheeselcoth	16.54	0.55	1.02	2.63
		November 20		
Open......	34.08	2.06	5.42	5.59
Lath......	26.06	1.35	3.30	2.84
Cheesecloth	21.94	1.25	3.57	2.15

[a] Results calculated and expressed as dextrose.

avoid grass growing in the immediate vicinity of manure droppings. The carbohydrate content of such a sample and a check sample taken nearby, both gathered May 1, 1924, is shown in Table 13.

TABLE 13.—*Pasture grass as affected by manure.*

Kind of sample	Dry weight	Pounds in 100 pounds of fresh sample Reducing sugars	Inverted sugars	Easily hydrolyzable carbohydrates	Total nitrogen
Unmanured	25.91	0.99	3.02	4.63	0.56
Near manure droppings	18.63	0.55	2.00	2.01.	1.08

From Table 13 it may be noted that the difference in carbohydrate compounds between these two samples of grass is much the same as the difference in composition between unshaded and shaded grass. If the unpalatability of grass growing around manure droppings be due to a reduction in the content of sugars and starches, then it is permissible to conclude that shaded grass may be less palatable than unshaded and for the same reason.

SUMMARY

The light in the old unfertilized pasture measured on four different dates ranged from 76 to 90% less than in the open field. The temperature, measured from August 23 to October 3, showed a range of 21.5°F. in the woods and 34.9° in the open. The temperature in the woods remained lower in the daytime and higher in the night. The evaporation, measured with black spherical atmometers from July 1 to October 21, inclusive, was 29.5% less in the woods than in the open.

Under these conditions of growth, the woodland pasture contained 32% more weeds than that grown in the open.

The woodland pasture yielded 85% less dry matter than that grown in the open.

The woodland pasture, pound for pound of actual bluegrass, contained 22% less total nutrients than that from the open pasture.

The amount of the total carbohydrates found in the green material of the native woodland grass was 38% less than that found in the native grass adjoining but grown in the open. The greatest difference found was in the inverted sugars.

The difference in quality found in the new seedings of woodland and open pasture confirms that found in the old pasture. The differences were even more marked, due probably to a greater density of shade in the woods.

The differences in quality of shaded and unshaded grass grown in the manured pasture, but shaded artificially, also confirm the differences found between the woodland and open pasture, thus indicating that in all three series the differences found in the quality of the grass were due chiefly to variations in the light.

The amount of carbohydrates found in grass grown around manure droppings was 47% less than that found in unfertilized grass near by. Since such grass is known to be unpalatable and since a similar reduction in carbohydrates was found in the woodland pasture, it is, therefore, permissible to conclude that there may be some basis in fact for the claim that woodland pasture is less palatable than that grown in the open.

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A SUGGESTION CONCERNING SOIL CLASSIFICATION[1]

A. B. BEAUMONT AND A. C. SESSIONS[2]

A great deal of the terminology of agriculture is the heritage of the remote past. This is especially true of the terms used in describing soils and tillage because they were among the first words to be used in the literature of agriculture. Modern agricultural science and art require a more exact and standardized terminology than that which prevailed and was adequate until some 50 years ago. This need has been met in part by the coining of distinctly new words and in many cases by an attempt to standardize the meaning of words that have been handed down in agricultural literature for hundreds of years. In this latter way it has been attempted to give standard meanings to the words used to designate soil classes.

Unfortunately, as Lyon and Buckman (8)[3] point out, some of the words have been permitted to take on a double meaning in soil classification. This leads to confusion. Those of us who have had experience in teaching soil classification fully appreciate the truth of this assertion.

The words *sand* and *clay* are used by most writers on soil technology or edaphology to designate both the soil separate and soil

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[1] Contribution from the Department of Agronomy, Massachusetts Agricultural College, Amherst, Mass. Received for publication January 11, 1926.

[2] Professor of Soils and graduate assistant, respectively.

[3] Reference by number is to "Literature Cited," p. 246.

class. That is, *sand* may be any one of the four grades of sand between 1.0 mm. and 0.05 mm. in diameter, and containing no silt or clay particles, as given in the classification of the U. S. Bureau of Soils (2); or it may be a mixture of sand, silt, and clay particles, provided the sum of the percentages of silt and clay is less than 20. Similarly, *clay* is used as a name for a *separate* and a *class*. In addition, geologists use the word clay to represent a material of rather definite chemical composition, a hydrated aluminum silicate. The word *silt* is not similarly used in a double sense except by writers who apparently make no claim to adherence to any strict terminology of soil classification.

In the teaching of soil science this ambiguity is disconcerting to say the least. No sooner is the student taught that *clay* means a group of particles whose dimensions lie within certain limits than he is requested to learn that it may also have the meaning of a group of particles including clay, silt, and sand separates. Surely good pedagogy demands that this inconsistency of terms and meanings be eliminated if possible.

With the hope that some light might be thrown on this problem of soil classification and some solution suggested, the senior author has for the past few years, with the help of graduate students,[4] studied data on mechanical analyses of soils reported in Field Operations by the Bureau of Soils of the United States Department of Agriculture. During the years 1903 to 1915 thousands of soils were analyzed mechanically by the Bureau, and those analyses of the alternate years 1903, 1905, 1907, 1909, 1911, 1913, and 1915 were selected as giving a representative cross section of the entire soil population surveyed during that period. In all, 5,876 soil analyses were studied and particles of each soil divided into three groups making a population of 17,628 groups of particles. The total sands (2.0 to 0.05 mm.), silt (0.05 to 0.005 mm.), and clay (0.005 mm.—) separates make the three groups.

The data collected are too voluminous to present except in a summary which is given in Table 1, and shown graphically in Fig. 1.

An examination of these data shows that there were no soils among those studied which were composed entirely of silt or clay particles and only a few made up entirely of sand. Of the 72 samples containing 95 to 100% sands many were beach sand or other sands of little or no agricultural value. It is reasonable to conclude from the data considered that less than 0.1% of our agricultural soils are composed entirely of sand particles. Of the five soils showing 75% clay three were subsoils and two were of the same type. No soil contained more than 85% silt.

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[4] Credit is given Messrs. A. S. Mallorey, A. L. Gray, and W. G. Buchanan for help in collecting the data.

In general, there are more soils containing large amounts of coarse particles than fine particles, and conversely, more containing small amounts of fine particles than coarse. In other words, soils containing large amounts of sands occur more frequently than those containing large amounts of silt and clay; and soils containing small amounts of silt and clay occur more frequently than those containing small amounts of sands. This distribution in a general way supports the conclusion of Jennings (6) that loam as defined by the Bureau of Soils is the prevailing class in the United States.

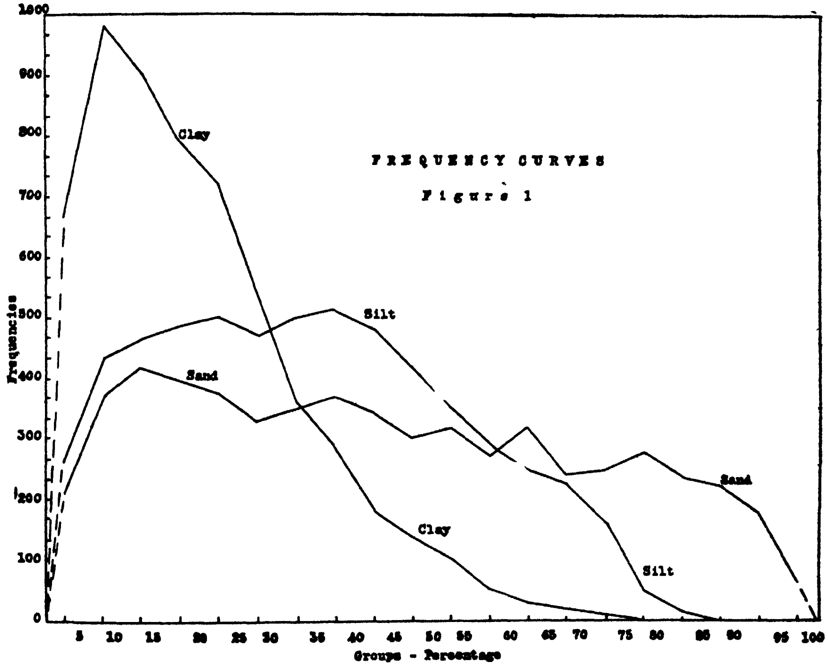
TABLE I.—*Summary of analyses.*

Groups Percentage of separates	Frequencies Number of separates		
	Sand	Silt	Clay
0–5	204	275	677
6–10	389	451	994
11–15	408	439	911
16–20	402	480	826
21–25	374	501	720
26–30	335	480	552
31–35	352	497	368
36–40	360	507	277
41–45	334	488	182
46–50	299	413	136
51–55	317	350	116
56–60	272	295	52
61–65	324	356	33
66–70	148	222	21
71–75	258	154	6
76–80	284	50	2
81–85	239	16	1
86–90	228	0	2
91–95	179	0	0
96–100	72	0	0

From data submitted the general conclusion may be drawn that in the United States soils of agricultural value composed entirely of clay, silt, or sands are practically non-existent and that those containing more than 75% clay, more than 85% silt, or more than 95% sands are negligible in number and area.

This deduction may serve as a basis for recasting our scheme of textural classification of soils. Whitney (16) in 1911 gave us our present scheme of classification. It appears that he used as a basis the averages of the results of mechanical analysis of 8,664 samples of soil collected in the soil survey, and that limits of the classes were arbitrarily chosen in such a way as to approximate the classification given by field men. In other words, the present scheme was intended to standardize the prevailing conception of soil classification held by field workers at that time. Whitney's classification is shown in Table 2.

It will be noted that there are twelve classes of soils, some of which indicate fine distinctions. In recent years a marked tendency has been shown by soil survey workers and others to extend the number. of fine distinctions of classification. This is of course a natural development in a specialized field, but one which should be carefully scrutinized. For some years agronomists have been questioning this trend toward a complex textural soil taxonomy. C. B. Lipman in a foreword to a paper by Pendleton (12) expressed an opinion held to a greater or less degree by others when he wrote, "Such minute classification and subdivision, in view of the present state of our knowledge of soils, is analagous, in my opinion, to carrying decimals out to four places when it is known that the accuracy of the method makes it impossible for them to be correct beyond the first decimal place." Also, Stevenson and Brown (15) have noted this tendency toward minute distinctions and deplored it. It appears



to the present writers, however, that some experienced field workers can differentiate between sandy clay and sandy loam, clay loam and silty clay loam, loamy sand and sandy loam. Moreover, we believe that the field worker can detect taxonomic soil differences that are within themselves of no particular significance so far as plant growth is concerned.

TABLE 2.—*Classification of soil material.*

(From instructions to field parties, U. S. Bureau of Soils, 1914.)

I. Soils containing 0–20 silt and clay:	
Coarse sand	25+fine gravel and coarse sand, and less than 50 of any other grade.
Sand	25+fine gravel, coarse and medium sand, and less than 50 fine sand.
Fine sand	50+ fine sand, or —25 fine gravel, coarse and medium sand.
Very fine sand	50+very fine sand.
II. Soils containing 20-50 silt and clay:	
Sandy loam	25+fine gravel, coarse and medium sand.
Fine sandy loam	50+fine sand, or —25 fine gravel, coarse and medium sand.
Sandy clay	— 20 silt.
III. Soils containing 50+silt and clay:	
Loam	- 20 clay, — 50 silt.
Silt loam	—20 clay, 50+silt.
Clay loam	20-30 clay, —50 silt.
Silty clay loam	20-30 clay, 50+silt.
Clay	30+clay.

The size of the particles of the different grades adopted by the bureau and used in the mechanical analysis work are as follows:

Grade	Millimeter
Fine gravel	2.0 to 1.0
Coarse sand	1.0 to 0.5
Sand	0.5 to 0.25
Fine sand	0.25 to 0.1
Very fine sand	0.1 to 0.05
Silt	0.05 to 0.005
Clay	0.005 to 0.0001

[a] The figures in this table represent percentage; the minus (—) and the plus sign (+) represent less or more: and the sign (-) when used between two figures, thus, 20–50, giving limiting values, should be read from 20% to 50%.

The thesis that fine textural differences in soils have no significant effect on plant growth is hardly capable of proof because of the many other ecological factors affecting the plant. There is, however, considerable evidence in support of the statement. So much has been reported in the literature showing the great variability of texturally uniform soils as measured by crop response that such variability is ordinarily accepted as a normal condition. Morgan (10), Lyon (7), Mercer and Hall (9), and, recently, Summerby (14) have reported results showing the great variability in plats on experimental fields selected because of uniformity. From such results there has come the rather common practice of replicating field plat treatments in order to decrease field error.

The variability within the types of soil is further shown by a study of many of the long-term experiments. For example, 20-year average yields of corn from check plats on Miami silty clay loam at Germantown, Ohio (11), show a coefficient of variability[5] of 7.87% and an extreme difference of 35.5%. Variation in yield on soils mapped as of the same type but separated somewhat geographically is shown by the following yields of corn from check plats on Miami silty clay loam: Germantown (20-year average), 39.3 bu.; Findlay (20-year average), 29.8 bu.; Madison (3-year average), 51.1 bu. The crop rotations used were similar but not identical. Also, from three fields in Illinois (5) located on brown silt loam of the Upper Illinoisan glaciation come results showing wide variations in type. Seven-year average yields of corn are: Aledo, 56.9 bu.; Carthage, 27.6 bu.; Clayton, 33.2 bu. The conspicuously better yield of check plat 8 of the general fertilizer series of the Pennsylvania (3) experiments might be mentioned, as well as the relation between check plats 6 and 12 of the south soil test of the Massachusetts (4) Station. Plats 12 and 6 are contiguous diagonally, but as an average of 13 crops of corn through a period of 30 years, the yield of plat 12 was 30.9% higher than that of plat 6. Such instances of soil variability no doubt could be multiplied by an extended review of published data, while also many cases of uniformity could be cited.

Many workers think that those soil differences which serve to differentiate series are more important than small textural differences. Structure, chemical composition (especially lime content), organic matter, and topography are often the primary factors determining plant growth. There is an extensive literature bearing on this phase of variability and no attempt is made here to treat the question comprehensively, although a few citations will be made. Lyon (7) attributes much of soil variability to very slight differences in structure. Skinner (13) has recently cited evidence showing considerable differences in the yield, size, and quality of pecans grown on soils of the same texture but different series. Brown (1), citing data from Iowa experiments to refute the statement of C. B. Lipman that the "variability of all soils and plants renders the data from any given fertilizer plot of value only on the plot, etc.," shows a greater variation between the Webster and Grundy silty clay loams than between the silt loam and silty clay loams of the Grundy series.

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[5] Using Bessel's formula.

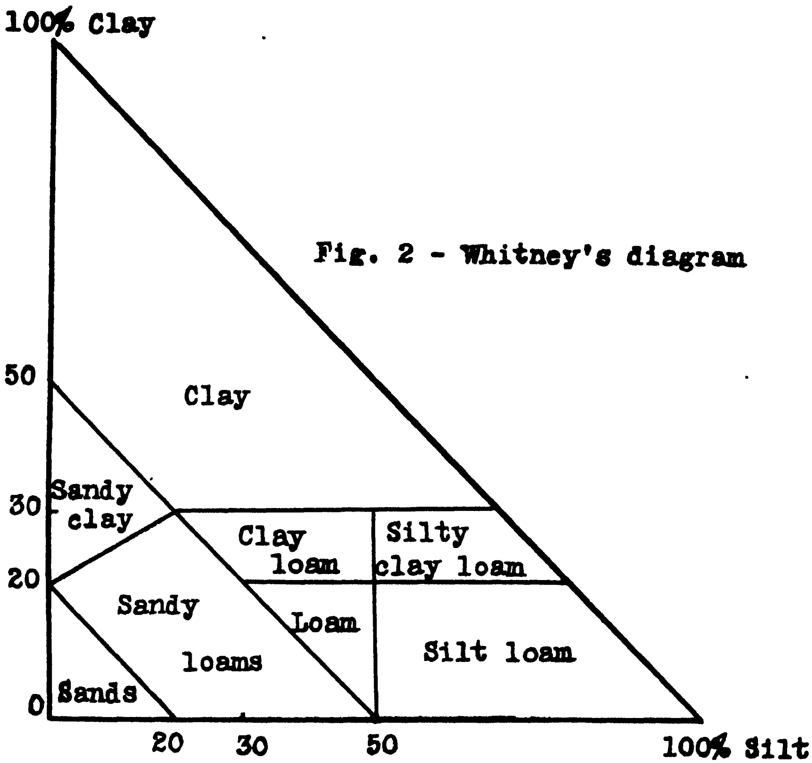

Fig. 2 - Whitney's diagram

It seems logical to conclude from data at hand that other ecological factors affecting plant growth may be so much more important than slight differences in texture of soil that it is futile to attempt to give them significance. Why not eliminate such textural niceties in the interest of simplicity?

We suggest for discussion the following revision of our scheme ot soil classification as the next step in its evolution: The word *loam* is a good Anglo-Saxon word which was used rather loosely until about the middle of the eighteenth century when it found its way definitely into agricultural literature. Let *loam* be used in the same sense as at present, i.e., a good soil textually, containing no group of particles in excess; but make a slight change in its range as indicated below. Eliminate *sand*, *clay*, *silty clay loam*, and *sandy clay*. There will then be left *loam*, the central basic class, and the modifications, *sandy loam*, *silt loam*, and *clay loam*. (See Tables 2 and 3 and Figs. 2 and 3.)

A study of the tables and figures will bring out the fact that in addition to the elimination of certain class designations there is some

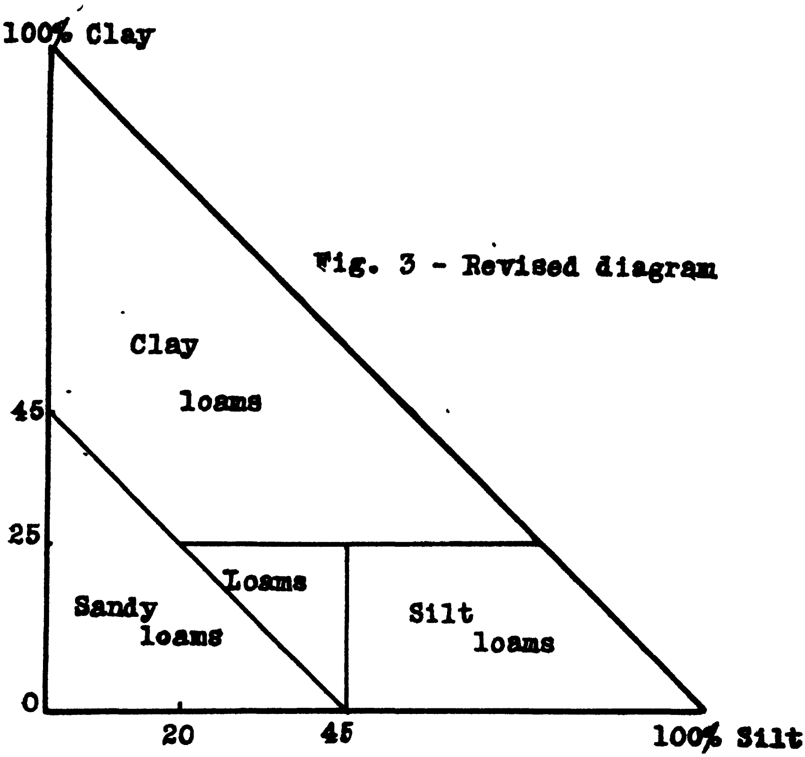

Fig. 3 - Revised diagram

shifting of limits. The clay and silt limits of the sandy loams are reduced five units, and those of the clay loams and silt loams extended five units. The clay limit for loams is extended five units and its silt limits are moved five points downward. This shifting of limits has the support of some field workers who feel that such a change would tend to simplify field work.

This revision has the advantage of eliminating the troublesome ambiguity between *separate* and *class* names and fine textural distinctions which are thought to be insignificant from the standpoint of plant response. The suggested classification gives a range of classes sufficient to meet the ordinary needs of description. Finer distinctions can, when occasion demands, be made by using such descriptive terms as *fine*, *coarse*, *medium*, *light*, and *heavy* in connection with the standard class names. Also, where extremely fine textural distinctions are demanded, they can be made by publishing the mechanical analysis, which, after all, gives the only accurate description of soil texture and should be more frequently reported. There is a notable lack of uniformity in the use of class names of soils. What one farmer calls a silt loam another may designate a clay. Even trained soil surveyors often disagree on some of the finer distinctions (15).

TABLE 3.—*Revised and simplified classification of soils.*

I. Soils containing 0–45% silt and clay.
   Sandy loams.
II. Soils containing 45+–100% silt and clay.
   1. Loams: 0–25% clay, 20+–45% silt.
   2. Silt loams: 45+–100% silt, 0–25% clay.
   3. Clay loams: 25+ 100% clay, 0–75% silt.

SUMMARY

A statistical study of mechanical analyses is submitted which shows that agricultural soils are composed of mixtures of soil separates rather than any one group of particles known as a separate, and that agricultural soils containing more than 75% clay, more than 85% silt, and more than 95% sands are negligible in number. The confusion due to ambiguity attached to the words *silt* and *clay* is pointed out. Evidence of variability in soils and the failure of plants to respond to slight textural differences in soils is given. Finally, a revision of the textural classification of soils is suggested which would eliminate the troublesome ambiguity and tend to check the multiplication of class names.

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THE SERVICE OF STATISTICAL FORMULAE IN THE ANALYSIS OF PLAT YIELDS[1]

J. ARTHUR HARRIS[2]

INTRODUCTORY

For many years I have watched with satisfaction the progress in scientific method which has at least accompanied, if indeed it has not been largely the product of, the activities of the American Society of Agronomy.

From the national standpoint, the agronomist has a most important function to fulfill. The increase in agricultural production which is essential if a rapidly growing population is to be maintained in physical fitness, and with leisure for mental productiveness, can be realized only by the more intensive application of scientific method in three interrelated fields of agricultural research and practice. Without attempting the difficult task of arranging them in the order of their potential economic importance, we may note that these are: (a) The extension of productive acreage through the various processes generally designated as reclamation; (b) the increase in the effectiveness of all methods of cultivation, fertilization, harvesting, storage, transportation, preservation, and marketing; and (c) the importation of species or of agricultural varieties suitable for special purposes, or suitable for cultivation under special conditions, and the improvement of existing varieties and the development of new forms by breeding.

In all of these lines, but particularly in the second and third, advance must rest primarily upon the results of quantitative experimentation, which for convenience may be divided into two phases, *viz.*, laboratory (including greenhouse) experimentation and field trials.

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[1] This paper was presented by invitation as a part of the symposium on "Applications of Statistical Methods to the Results of Plat Tests" at the meeting of the Society held in Washington, D. C., November 21, 1922. Revision for publication has been delayed by other duties. Certain more recent results have been included. Received for publication January 18, 1926.

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An essential feature of the experimental method is that it seeks by the elimination of all but a single factor, and by the variation of this factor, to determine the proximate cause of phenomena. Because of the relative ease with which conditions may be controlled and modified, laboratory and greenhouse experimentation is bound to play a large rôle in future agronomic investigation. Because of the great difficulty of controlling conditions and of varying any given factor in crop production in the field, the plat test is destined to be superceded, as experimentation with agricultural plants becomes more refined, in many instances by pot cultures and other greenhouse experiments and by individual performance tests. It is only by these more refined technics that the more difficult problems of the factors underlying plant growth can be solved. It is here that agronomy must make its intimate contact with plant physiology and chemistry.

But simultaneously with the replacement of field trials by more exact laboratory and greenhouse experiments in certain lines of research, the number of phases of agricultural practice which must be subjected to critical examination will so increase that in the future the plat test may be expected to hold an increasingly important place in agricultural science. There are, indeed, a great number of problems which can be solved by field trials alone. Agronomy has an immediately practical function. Conclusions drawn from laboratory experiments must be tested in the field before recommendations concerning practical application under diverse soil or climatic conditions can be based upon them. Furthermore, laboratory research alone can never determine the best practical methods of planting fertilization, tillage, harvesting, and marketing—operations which involve economic considerations, particularly labor, as well as biological factors.

The plat test seems destined, therefore, to have continually increasing importance in agricultural work. One of the greatest advantages of the plat test is that experiments are carried out under conditions simulating those of ordinary agricultural operations. Results obtained by this method have, therefore, an especial appeal for those who are accustomed to thinking in terms of yield per acre. This fact alone is sufficient to insure the permanence of the plat test as a method of agricultural experimentation.

The development of special methods for plat testing has an importance not merely in agronomy as such, but in plant breeding.

In their enthusiasm for the application of the methods of endless recombination made possible by Mendelian theory, plant breeders have too often lost sight of the fact that the practically important end is merely to obtain varieties which will meet best the requirements of a particular set of conditions. It is quite possible that types as well adapted to these ends as those which can be made by hybridization are already in existence. It is of fundamental importance, therefore, to determine by cruicial tests which variety of a series is most suitable. Dependable information of this kind is exceedingly meager, even in the case of our most important agricultural crops. Better knowledge can be obtained only by (a) improvement in agronomic technic and by (b) the application of adequate statistical criteria to the results of extensive experimentation.

That the variety tests and fertilizer and tillage experiments hitherto carried out by our agricultural institutions by means of plat cultures have been of material value is perhaps beyond question. But unstandardized and based on no scientific system of probable errors, they have also been the means of the waste of incredible amounts of public funds in experimentation alone to say nothing of the losses which ill-advised recommendations may have entailed in practical agriculture. Piper and Stevenson (24)[3] are probably right in the suggestion that the recognizedly large sources of error in field experiments have had a retroactive influence on the experimentalists themselves and thus led to unnecessary carelessness in experimentation, and even to the suppression of results which did not coincide with current theories.

The real significance of the plat test, and the full importance of an effort to secure standardization of method, freedom from biological experimental errors, and adequacy of statistical analysis, will be clear when it is realized that every series of plat tests is unconsciously made a basis for generalization. For example, an acre is divided into 10 or 20 plats and each plat is sown to a different variety. The yield of these varieties is compared and the best variety selected, at least preliminarily, on the basis of this test. This means that a prediction is made concerning the yield which this acre would produce, or which a hundred thousand acres would produce, if planted to this variety. Thus errors which appear insignificant when considered in terms of actual yields of small plats may be multiplied thousands, tens of thousands, or hundreds of thousands of times in practical agriculture, if unwarranted recommendations be based upon them. There is grave danger in thinking in terms of plat yields only. The investigator should occasionally think in terms of the yields of large agricultural regions—in terms of the potential economic importance of the recommendation made. This will bring home to the worker the realization that his variety or plat yields must be fully tested by an adequate system of probable errors before recommendation is based upon them.

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[3] Reference by number is to "Literature Cited," p. 272.

If agronomy is to rank as a science and to be of the highest practical value, the methods of experimentation and the formulae used for interpretation of experimental results must be unimpeachable.

What service may statistical formulae render in a field of such importance?

It is not possible to answer this question in full in the course of a brief address; neither is it practicable to refer, even by name alone, to all those who have contributed toward the solution of the problem—either by the accumulation of careful experimental records or by their attempts at the description or analysis of their data by statistical methods

Instead of attempting the impossible and largely unprofitable task of reviewing in outline all that has been done in this field, I shall attempt merely to indicate the different ways in which statistical methods may be of service in the interpretation of plat test data.[4]

VARIOUS APPLICATIONS OF STATISTICAL FORMULAE IN THE ANALYSIS OF PLAT TEST RECORDS

THE PROBABLE ERRORS OF PLAT YIELDS

In earlier agronomic experimentation it was tacitly assumed that to compare a number of different fertilizers or a series of varieties it was merely necessary to devote a plat to each and to inspect the yields in order to arrive at valid conclusions concerning the relative value of varieties or of cultural methods.

The common experience of agronomists early showed, however, that the yields of a series of plats differ greatly among themselves. A pair of plats similarly treated may be expected to yield considerably different results, even when the soil appears to be uniform and experimental conditions are carefully designed to reduce errors in harvesting and measurement. The investigator desires to know whether an observed difference between the yield of two plats, or of two series of plats, may be reasonably regarded as due to the influence of the factors under investigation, e. g., the varieties grown or the cultural routine, or whether it is merely of the order to be expected as a result of the influence of uncontrollable factors to which the inherent variability of plat yields is due.

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[4] Since some of the results to be given have been treated in detail before, I have cited earlier papers of my own in which formulae are developed or illustrated, and in which the work of others is cited and discussed.

To answer the questions he requires the coöperation of the statistician.

The statistician as such can do nothing whatsoever to eliminate the individuality of the plats to which these differences are primarily due, or to minimize the experimental errors of measurement upon which they to some extent depend. These are problems of agronomic technic which must be solved by the agricultural experimentalist. The statistician can, however, furnish criteria of the trustworthiness of statistical constants based on series of yields of known variability and number. These criteria are the so-called *probable errors*, or more precisely *probable errors of random sampling.* Such probable errors are entirely statistical in nature and have nothing whatever to do with the *possible errors* of measurement, except in so far as these constitute an irreducible part of the variability of the plat yields. They assume the technical or biological correctness of the variable observations and measure merely the degree of trustworthiness of statistical constants based on series of observations [5]

The fact of the variability of plat yields and the significance of this variability for the interpretation of the results of experimentation was not at first fully enough recognized by agronomists. The more progressive of the students of field crops are now awaking to the realization that experimental results without probable errors are of little significance.

In this field the work of Wood and Stratton (25) and of Mercer and Hall (23) have had a far reaching influence. While the paper by Wood and Stratton contained nothing essentially new to the biometrician, it first focused the attention of agronomists sharply upon the orderliness of variations in experimental results. The data of Mercer and Hall made possible further advances in the analyses of this problem. In this country Love has done much to draw the attention of agriculturists to the necessity for considering the probable error of their experimental results.

While theoretically the probable error of plat tests should be computed in the same manner as any other probable error, there are complicating factors which have not been fully appreciated by many of those who have written in this field. The remainder of this paper will be devoted to a consideration of some of these factors.

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[5] It must not be inferred from this statement that the statistician blindly accepts data without criticism. One of his tasks is to discover inherent defects due to faulty biological experimentation. As a matter of fact the demonstration of much of the weakness of the plat experimentation of the past is due to such critical statistical examination.

THE PRACTICAL UNIVERSALITY OF FIELD HETEROGENEITY

While in the earlier history of our agricultural experiment stations sites were selected with little reference to the uniformity of the fields upon which comparative tests were to be made, there has been in recent years a growing consciousness among agronomists of the fact that the diversity or heterogeneity of experimental fields is one of the chief sources of the variability of plat yields which renders the correct interpretation of the results of agricultural experimentation so difficult. This has found expression in efforts to select more uniform experimental tracts, to duplicate or replicate tests with a view to averaging out the influence of the irregularities of the soil, and even to correct the influence of this source of error by referring all yields to a standard series.

My own attention was sharply focused upon the fact that even in very small areas the irregularities of the soil may be such as to obscure the biological differences under investigation by an experiment designed to measure the relationship between the weight of the bean seed and the character of the plant which it produces. In this experiment made in 1907 the seeds were planted in the order of their weight classes across a small plat carefully selected for its apparent uniformity. The results indicated a negative correlation between seed weight and the number of pods on the plants produced (8). Other cultures in which the seeds had been distributed at random over the experimental field to eliminate the influence of substratum heterogeneity (4) had indicated a positive correlation (7, 10).

The only logical explanation of this inconsistency appeared to be an influence of otherwise unapparent irregularities of the substratum. This view was strengthened by the very low values of the correlations between the yields of varieties of cereals throughout a period of years (5) and of the correlation between the characteristics of varieties of peas grown in different seasons (11). It was also the basis for the surmise that differences held by writers to represent differentiated "pure lines" may be due to uncontrolled irregularities of the experimental field (3).

But it is not sufficient merely to recognize the existence of substratum heterogeneity as a factor which may influence experimental results. It is a prerequisite of progress to differentiate this factor from others which may produce irregularities in the experimental results and to secure a measure of field or substratum heterogeneity as expressed in terms of the physical or chemical properties of the soil which may influence plant growth in terms of the consequences of these diversities of the soil as expressed in the crop. Such a measure to be of the greatest value must be not merely universally applicable but universally comparable. It is essential to remember that this is a very different problem from the mere measurement of the variability of plat yields, which may be in part due to soil irregularities and in part to the action of one or more of a multitude of other factors.

As so often happens in science, the securing of an adequate criterion was dependent on work directed to quite different ends. The fundamental steps were taken in the suggestion that means, standard deviations, and correlation coefficients may be most advantageously calculated in terms of moments taken about zero as origin (1) and in simple methods for the formation of correlation tables (2) and condensed correlation tables (6) when the number of possible combinations is large. These led to the development of a system of intra-class and inter-class correlation formulae (9), which as a special case furnish a measure of the heterogeneity of the field (12) in terms of the correlation between the characteristics of closely associated plats. This coefficient has the advantage not merely of universal applicability and comparability but of becoming 0 if the factors producing variations in the characteristics of the plats are not sufficiently potent to influence the characteristics of associated plats. The size of the plats and the number of plats combined is at the will of the experimenter. The application of this formula to wide series of agronomic data has shown (14) that practically without exception the most carefully selected fields are heterogeneous to a degree which influences profoundly the yield of the crops grown.

That the influence of soil factors is not limited to gross crop yields is shown by investigations on cotton in which it has been found that there is a material correlation between adjacent plants for such physicochemical properties of the leaf tissue fluids as osmotic concentration in terms of freezing point depression, specific electrical conductivity, ratio of specific electrical conductivity to freezing point depression, and hydrogen-ion concentration (20). Evidence that these correlations are in part due to heterogeneity of the soil with respect to salinity is afforded by the fact that comparable correlations are found for both chlorides (21) and sulfates (19). To this point I shall return later.

The accuracy with which the coefficient of field or substratum heterogeneity represents the diversity of the field in terms of the relationship between the characteristics of associated plats will be

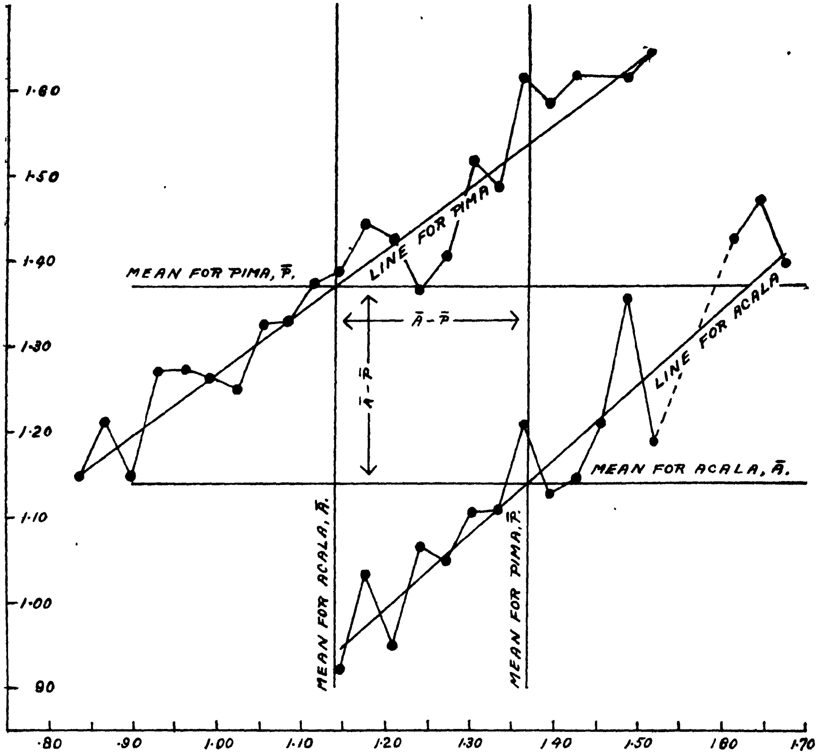

FIG. 1. Regression of freezing point depression of Acala cotton on freezing point depression of Pima cotton and regression of freezing point depression of Pima cotton on freezing point depression of Acala cotton when the two varieties are grown in immediate association.

emphasized by a consideration of the orderliness of the distribution of the means of the plats considered as a dependent variable of a pair associated with the plats considered as the independent variable of the pair. A number of such series of means with their accompanying regression lines were given in the original paper.

In addition to these we have more recently determined the form of the regression line for the correlation between the freezing point depression, Δ, specific electrical conductivity, K, ratio of specific electrical conductivity to freezing point depression, K/Δ, and chloride content, Cl, in the leaf tissue fluids of the crop grown upon the soil of a saline experimental field (18) on the basis of data collected for the Office of Alkali and Drought Resistant Plant Investigations, the Office of Biophysical Investigations, and the Office of Western Irrigation Agriculture of the Bureau of Plant Industry.

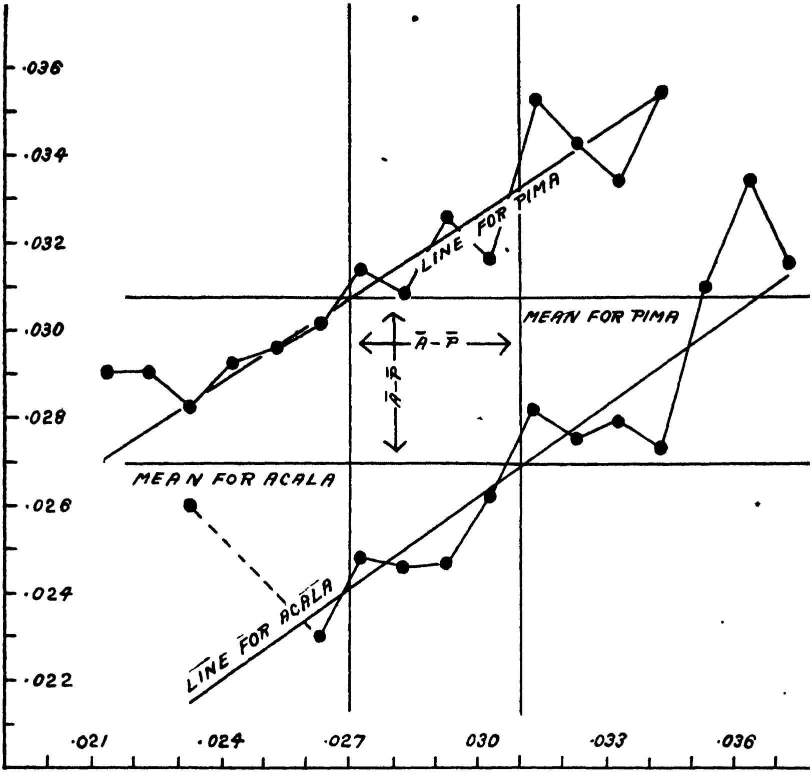

Fig. 2.—Regression of specific electrical conductivity of Acala cotton on specific electrical conductivity of Pima cotton and regression of specific electrical conductivity of Pima cotton on specific electrical conductivity of Acala cotton when the two are grown in immediate association.

Fig. 1, shows the mean freezing point depression, Δ, of Acala cotton (scale of ordinates) associated with Pima cotton of given freezing point depression (scale of abscissae) and of Pima cotton (scale of ordinates) when grown in immediate association with Acala cotton (scale of abscissae). Note that the two scales serve for both varieties, but that the legends indicate to which variety the straight lines and the empirical means pertain. Fig. 2 gives similar results for specific electrical conductivity, K. Finally, Fig. 3 shows the mean chloride content, Cl, of Pima cotton when grown in close association with Acala cotton of given chloride content as shown by the scale of abscissae and of Acala cotton when grown in close spatial association with Pima cotton of the chloride content shown by the scale of abscissae.

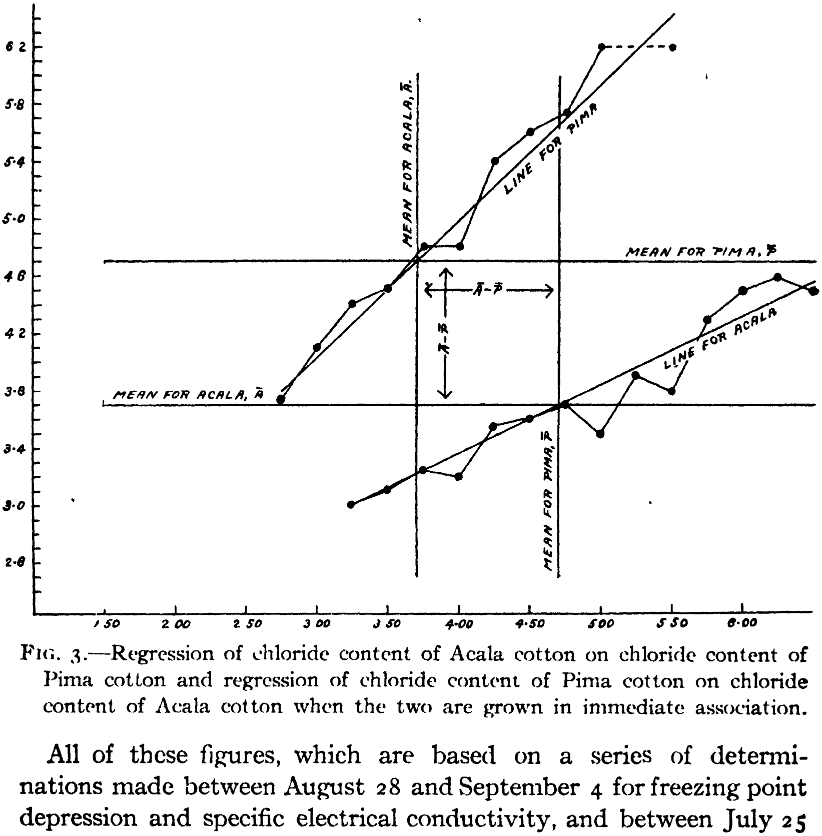

FIG. 3.—Regression of chloride content of Acala cotton on chloride content of Pima cotton and regression of chloride content of Pima cotton on chloride content of Acala cotton when the two are grown in immediate association.

All of these figures, which are based on a series of determinations made between August 28 and September 4 for freezing point depression and specific electrical conductivity, and between July 25 and August 9 for chloride content, not merely indicate excellent fits of the straight lines when the smallness of the number of observations is taken into account, but they also show clearly the differentiation of the types of cotton with respect to total solutes and conducting solutes (20) and to a specific ion (21). This differentiation is shown by the wide separation of the two lines with their associated empirical means and by the distances between the means themselves.

Up to this stage of development these results have had a three-fold importance.

First, they have served to emphasize the great difficulty of securing suitable experimental fields. Practically all of the fields involved in our first study, and shown to be highly heterogeneous, had been accepted by competent agronomists as satisfactorily uniform for experimental work. It is clear that greater care in this phase of agricultural experimentation is essential.

Second, they furnish evidence for a high degree of lawfulness of variation within a heterogeneous field, and thus justify an effort to push further the statistical attack upon these problems. The linearity of the relationship between associated plats furnishes additional proof of the statistical validity of the coefficient of substratum heterogeneity proposed a number of years ago.

Third, they have shown the necessity for the application of corrective terms in the calculations of the probable errors of differences in yield, or other characteristics of the crops grown. The standard deviation of the differences between the crop yields or other characters of the two varieties, or methods of treatment under comparison, say *a* and *b*, is given by

$$\sigma^2_{(a-b)} = \sigma^2_a + \sigma^2_b - 2r_{ab}\sigma_a\sigma_b$$

where σ denotes the standard deviations and r the correlations of the two variables. This point has been fully illustrated in the papers cited above.

THE PERMANENCE OF DIFFERENCES IN THE PLATS OF AN EXPERIMENTAL FIELD

The heterogeneity of the field is measured by determining the correlation between the yield of a single crop, or of a pair of crops, on closely associated plats of the same field.

If the yields of a series of plats be available for two or more years, it is possible to ascertain whether the differences between them are of a purely ephemeral nature, or whether they are persistent from year to year, by determining the correlation between homologous yields in the two years as first suggested a number of years ago (13).

Scofield and I have shown (22) that for a series of uniformly cropped plats[6] under irrigation at Huntley, Montana, there is a significant correlation between the yield throughout a series of years.

During the period 1911 to 1919, inclusive, 19 series of "yields" are available from these crops.[7] These comprised sugar beets, alfalfa, ear corn and silage corn, oats, and barley. From the records of these yields a series of 152 correlations between the production of the same plats in different years have been deduced. Of these,

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[6] These plats were 46 in number, each 0.17 acre in area, and were harvested as whole plats, half plats, or quarter plats. The whole field was seeded and treated as a unit until harvest time when the same plat boundaries were established year after year.

[7] This number results from the fact that grain and straw may be considered individually, or may be lumped together as a measure of total crop-producing capacity. Three cuttings of alfalfa were harvested in one instance.

133 are positive as compared with 19 which are negative in sign. The average value of the positive correlations is +0.333, whereas the average value of the negative coefficients is —0.148. The general average is +0.274.

The significance of the results may be further tested by determining the average of the correlation between any one crop and all the other crops grown. The results appear in Table 1. With the exception of the first crop grown (sugar beets, 1911), the correlation between the yield of each individual crop and the yields on the same plats in the eight other years of the experiment are on the average positive.[8]

TABLE 1.

Year and crop	Correlation	Year and crop	Correlation
1911, sugar beets	-0.077	1915, ear corn	+0.167
1912, total alfalfa	+0.242	1916, ear corn	+0.486
1913, alfalfa I	+0.346	1917, oat straw	+0.202
1913, alfalfa II	+0.403	1917, oat grain	+0.289
1913, alfalfa I and II	+0.441	1917, total oats	+0.293
1914, alfalfa I	+0.401	1918, silage corn	+0.226
1914, alfalfa II	+0.354	1919, barley grain	+0.141
1914, alfalfa I and II	+0.407	1919, barley straw	+0.086
1914, alfalfa III	+0.366	1919, total barley	+0.126
1914, alfalfa I to III	+0.428	General average	+0.274

A study of certain of the individual constants, represented in Fig. 4, increases confidence in the conclusion that there is a real similarity in yield of these small plats throughout a period of years. In this diagram the correlations of each crop, with the exception of oats and barley,[9] is shown on the scale of ordinates. In each panel is indicated the name and the year of growth of each crop correlated with the crops shown by the legends along the base line of the diagram.

The heavy line in each panel denotes zero correlation. Points above this line indicate positive correlation, while those below indicate negative correlation, as shown on the scale of ordinates. The values of the correlations between the yields of sugar beets and the yields of other crops are distributed with some irregularity about

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[8] The results which are available for the 92 half-plat and the 184 quarter-plat units substantiate in a general way those for the yields of the original areas. Thus, while the correlation is not very high, there can be no reasonable doubt of the existence of a relationship between the yields of a series of plats throughout a period of years.

[9] The two small grains are omitted primarily to save space. The coefficients showing the relationships between the yields of these cereals and all other crops are included in the vertical series of the diagram, but their inclusion in the horizontal series would merely increase the size of the diagram at the cost of considerable waste spaces.

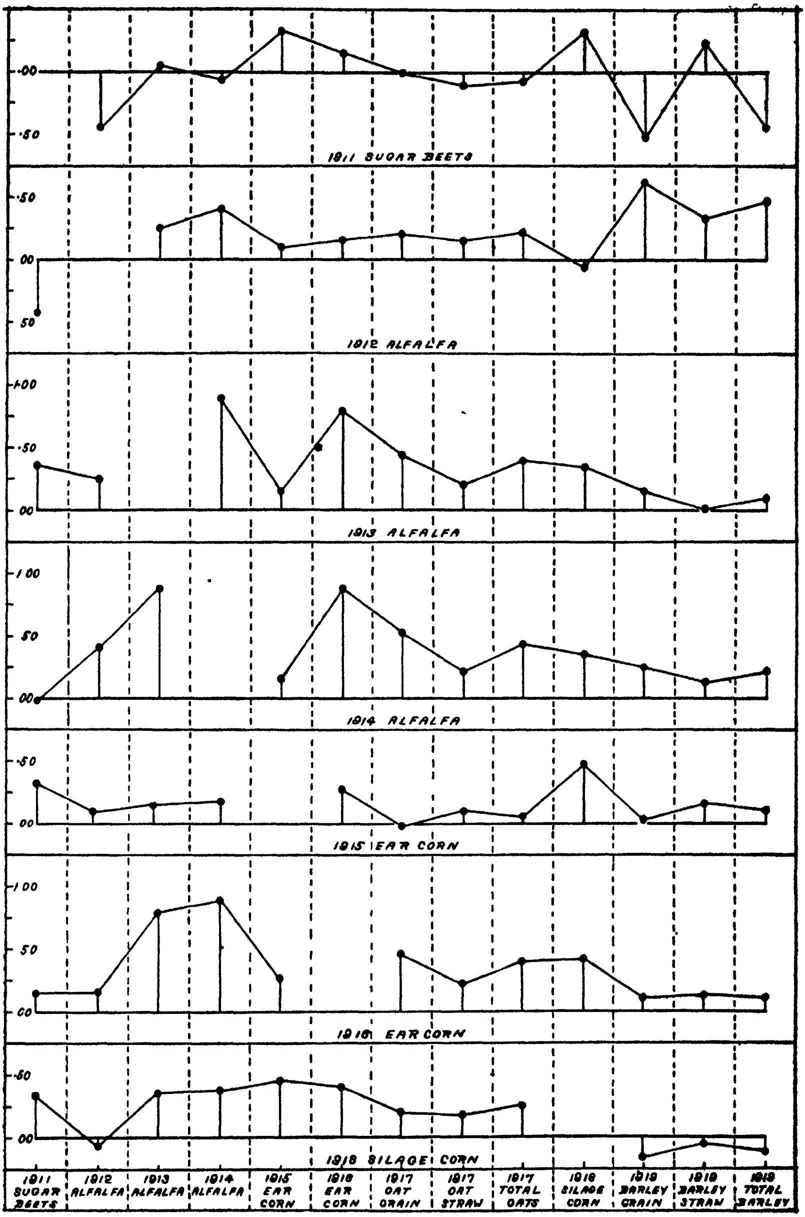

FIG. 4.—Distribution of the correlation coefficients measuring the relationship between the yields of the same plats in different years in experiments conducted by the office of Western Irrigation Agriculture at Huntley, Montana.

the line of zero correlation. The other correlations are clearly, conspicuously, and prevailingly positive.

These results show conclusively, therefore, that plats, even of the small size and apparent uniformity of those of the Huntley Station, are characterized by differences which may persist throughout a period of years. Thus plats which produce more in one year will, in general, produce more in another year. While this is a well-recognized principle for large areas, and is indeed the basis for the selection of agricultural land, its validity for small plats seems not to have been recognized before.[10]

The origin of the correlation between the yields of the same plats in different years may be attributed to initial physical or chemical differentiation of the plats or be referred to the influence of the crops grown upon the soil. Both of these factors will be discussed presently. For the moment it is sufficient to note that the inter-annual correlation for plat yields has been shown to be of material value in one long-continued series of careful experiments. It is evident that the correlation may make possible some attempt at the standardization of plats by the growing of a uniform crop antecedent to the use of the field for growing those representing a number of varieties, or of methods of fertilization or of cultural treatment.

It must not be assumed that it is the differences between relatively large plats only that are of importance in experiments with agricultural plants. Careful studies of the highly saline soils of the Gila River Valley of Southern Arizona have shown that there may be a material correlation between a first and second series of physiological measurements made in the same season, notwithstanding the intervention of a period of irrigation. This may be illustrated by Fig. 5 which shows the mean values of the chloride content of the leaf tissue fluids in terms of grams per liter in Pima Egyptian and Meade[11] and Acala Upland cotton in a first (July 25 to August 9) and second (August 28 to September 4) series of determinations made in 1922. The slopes of the lines indicate the intimacy of the correlation between the two determinations made on the same groups

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[10] The principle is probably not of unlimited applicability because of the fact that weather as well as soil plays a large part in determining yield. It is quite reasonable to suppose that certain soil conditions would give maximum yields under one set of weather conditions, but minimum yields with another set of aereal conditions. Low plats, for example, might be expected to yield poorly in years of excessive rainfall.

[11] The highly aberrant mean for Meade cotton is based on a single analysis which is probably erroneous, but it has been included to avoid any possibility of criticism of selection of data.

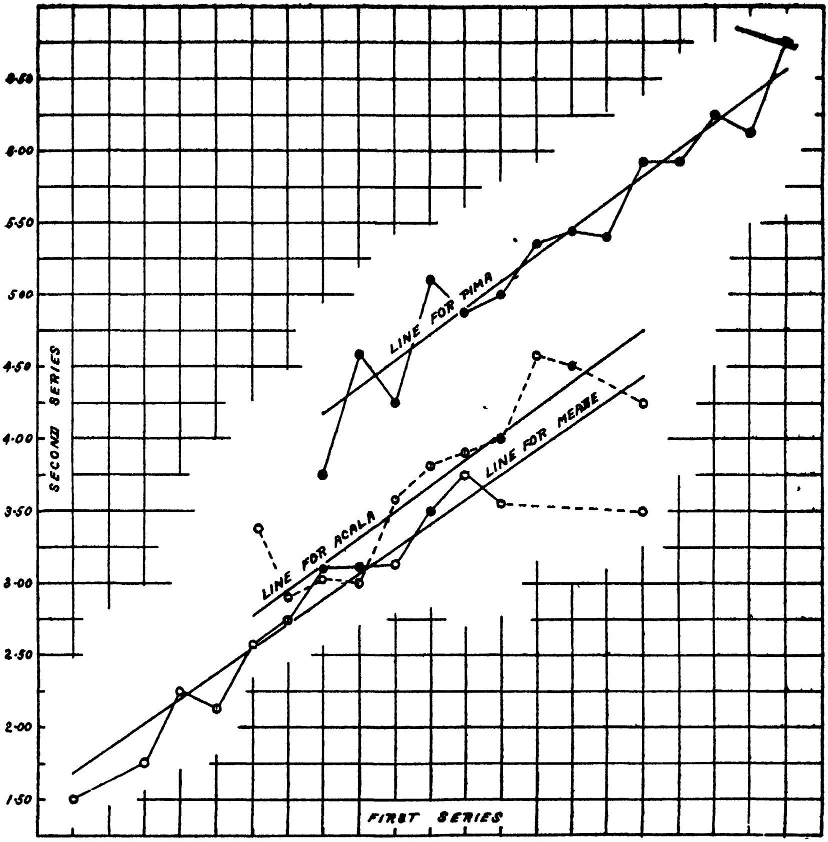

FIG. 5.—Regression of chloride content of second series of determinations (Aug. 28 to Sept. 4) on chloride content of first series of determinations (July 25 to Aug. 9) in Pima Egyptian (solid dots and solid line) and Meade (circles and solid line) and Acala Upland (circles and broken line) cotton grown on saline soils.

of plants distributed over the field. The relative position of the lines on the axis of ordinates indicates the differentiation of these varieties with respect to chloride content.

Such studies have not merely a theoretical interest. They are of importance in determining the probable errors of the differences between a first and second series of determinations with a view to ascertaining whether there is a change in the physiological state of the organism with the march of the season. Furthermore, it may in some cases be necessary to determine cross correlations between a first and second series of determinations in order to ascertain whether there is an increase or a decrease in the extent of the differentiation of the two forms. The formulae for the calculation of such probable errors have been given (15) and illustrated in the papers cited.

THE PHYSICAL AND CHEMICAL FACTORS TO WHICH FIELD HETEROGENEITY IS DUE

In the earlier stages of the investigation of the problem of field heterogeneity, it was necessary to limit attention merely to the differentiation of the plats of the field with respect to crop-producing capacity.

While the demonstration that (a) heterogeneity is a practically universal characteristic of the field which may be used for fertilizer tests, variety trials, or any other experimental purpose requiring plat yields, and that (b) the degree of heterogeneity is so great as to leave conclusions drawn from experiments carried out without proper regard to probable errors calculated without due regard to heterogeneity open to question, are the steps of the greatest immediate importance to the agronomist, a solution of the problem demands the determination of the proximate causes of the correlation between the yields of neighboring plats.

In the earlier stages of the work it was only possible to consider the correlation between certain physical and chemical characteristics of the soil of the plats into which a field may be divided. The results of these investigations (14) have shown that there is a material correlation between such soil characteristics as moisture and carbon and nitrogen content in closely associated plats.

As a first illustration of the chemical differentiation which may obtain between the parts of an experimental field, we may note that an analysis of the data of Waynick and Sharp has shown the following correlations between contiguous borings grouped in a 2 x 2-fold manner.

For silty clay loam at Davis

For carbon, $r=0.417 \pm .063$, $r/E_r=6.67$

For nitrogen, $r=0.498 \pm .057$, $r/E_r=8.75$

For blow sand at Oakley

For carbon, $r=0.317 \pm .068$, $r/E_r=4.65$

For nitrogen, $r=0.230 \pm .072$, $r/E_r=3.20$

Again the coefficients are positive, of a material order of magnitude, and probably significant in comparison with their probable errors.

For the correlations between the soil moisture determinations in a plat of the Office of Western Irrigation Agriculture at San Antonio the coefficients given in Table 2 have been found. The correlations range from +0.317 to +0.702. While there are only 88 borings, the coefficients may in every instance be considered statistically significant in comparison with their probable errors. Thus, notwithstanding the fact that we are dealing with a field of 130 by less than 264 feet, there is a very marked heterogeneity in respect to so important a factor in plant growth as soil moisture at every level from the surface foot to the sixth foot of soil.

As a final illustration, I may refer to a hitherto unpublished series of correlations based on an irrigated plat at the Cooperative Testing Station, Sacaton, Arizona (17). For the opportunity of carrying out these studies I am indebted to T. H. Kearney, Physiologist-in-Charge, Alkali and Drought Resistant Plant Investigations, and to G. N. Collins, Botanist in Charge of the Biophysical Laboratory, both of the Bureau of Plant Industry.

TABLE 2.

Depth	Correlation	r/Er
First foot	0.317±0.065	4.9
Second foot	0.529±0.052	10.2
Third foot	0.542±0.051	10.7
Fourth foot	0.702±0.036	19.4
Fifth foot	0.607±0.045	13.4
Sixth foot	0.484±0.055	8.8

Eighty borings were distributed in 4 rows of 20 each over a plat 400 by 26 1/2 feet. The soil resistance at approximately the same water content was determined by the soil bridge.

In analyzing these data we have determined the correlation between the resistances of the four adjacent borings which form the 20 short rows transverse to the long axis of the field. These coefficients have been computed in two ways. First, coefficients have been determined for the homologous borings of each pair of the long rows. This has been done to avoid a mathematical error due to the symmetry of the correlation surface (16). The close agreement of the two methods of calculations shows that this source of error is of no importance in the present case. Second, the coefficients have been computed as from a symmetrical table made up from all the possible permutations of the four borings in the transverse rows by the use of the usual heterogeneity formula.

The constants measuring the relationship between the resistances of soil from comparable depths and from the same section of the field but from different rows appear in Table 3.

The averages of the six coefficients representing the possible combinations of the four long rows are laid beside the coefficients deduced from all the possible permutations of the comparable readings for the four rows in Table 4.

Summarizing the results of these calculations, we may note the following:

The coefficients, however determined, are of a very substantial order of magnitude, and for the most part statistically significant. Because of the small size of the field they confirm in a striking manner the conclusions drawn from the examination of other series of data in showing that cultivated fields are characterized by marked heterogeneity with respect to the physical and chemical properties of the soil as well as of the crops which they produce.

The averages for various permutations of rows show that the correlations for contiguous rows are on the average higher than those for rows which are more widely separated. Thus, the average correlation between rows 1 and 3 is 0.602 as compared with 0.566 for rows 1 and 5 and 0.387 for rows 1 and 7. Again, the correlation between rows 3 and 5 is 0.802 as compared with 0.408 for rows 3 and 7. This dependence of the magnitude of the correlation on the closeness of the borings indicates the variation which may occur in the salt content of the soil through such a narrow space as the width (26.5 feet) of the plat.

TABLE 3.

	Second variable			
	Row 3	Row 5	Row 7	Average
First variable, soil of Row 1				
Resistance of first foot, Row 1	0.815	0.680	0.339	0.611
Resistance of second foot, Row 2	0.558	0.645	0.441	0.548
Resistance of third foot, Row 3	0.724	0.703	0.370	0.599
Resistance of fourth foot, Row 4	0.312	0.234	0.398	0.315
Average all layers	0.602	0.566	0.387	——
Average resistance, Row 1 to Row 4	0.890	0.768	0.514	0.724
First variable, soil of Row 3				
Resistance of first foot, Row 1	——	0.800	0.499	0.650
Resistance of second foot, Row 2	——	0.865	0.168	0.517
Resistance of third foot, Row 3	——	0.670	0.368	0.519
Resistance of fourth foot, Row 4	——	0.873	0.596	0.725
Average all layers	——	0.802	0.408	——
Average resistance, Row 1 to Row 4	——	0.881	0.480	0.681
First variable, soil of Row 5				
Resistance of first foot, Row 1	——	——	0.539	0.539
Resistance of second foot, Row 2	——	——	0.266	0.266
Resistance of third foot, Row 3	——	——	0.548	0.548
Resistance of fourth foot, Row 4	——	——	0.472	0.472
Average all layers	——	——	0.456	——
Average resistance, Row 1 to Row 4	——	——	0.561	0.561

TABLE 4.

	Correlations for all rows $r \pm E_r$	r/E_r	Average for pairs of rows
First foot	$+0.550 \pm 0.053$	10.460	0.6121
Second foot	$+0.349 \pm 0.066$	5.273	0.4903
Third foot	$+0.517 \pm 0.055$	9.367	0.5637
Fourth foot	$+0.408 \pm 0.063$	6.487	0.4808
First to fourth foot	$+0.581 \pm 0.050$	11.649	0.6824

The coefficient for the average resistance of the entire soil column, the average of the resistance readings for the 4 individual feet of soil, is higher than that for any individual foot. This may be due to the fact that experimental errors of the conductivity determinations are to some degree eliminated when the average value of the resistance for the 4 upper feet of soil is taken. It may be in part due to differences in the extent to which the salts have been brought to the surface in different parts of the field, because of differences in water content, or to other factors.

The average values of the coefficients measuring the relationship between the resistances of homologous samples from two individual rows are in all cases slightly higher than those deduced from a symmetrical table involving all the possible combinations of the rows. This difference is due to the influence of the mathematical factor referred to above (16), but the small size of the difference shows that the error due to the use of the field heterogeneity formula is not great in the present instance.

The intimacy of the correlations for the electrical resistance of the soil of adjacent plats, and the high degree of regularity which may be demonstrated in the variability of an experimental field, may best be illustrated by another but similar series of data derived from a large number of borings made in 1922 on plats about 6 x 10 feet in area.

The circles and solid dots of Fig. 6 show on the scale of ordinates the mean values of the electrical resistances of the soil mass of plats associated with plats of the resistance indicated on the scale of abscissae (18).

Notwithstanding the relatively small number of borings on which the determinations are based, the agreement between the actual means and the smoothed means as indicated by the straight lines is most satisfactory. The firm lines and solid dots represent the relationship for plats in immediate juxtaposition, while the broken lines and circles represent the relationship for plats which are separated by an intervening (10-foot) plat. The slope of the broken line is less than that of the firm line, showing the decrease in correlation

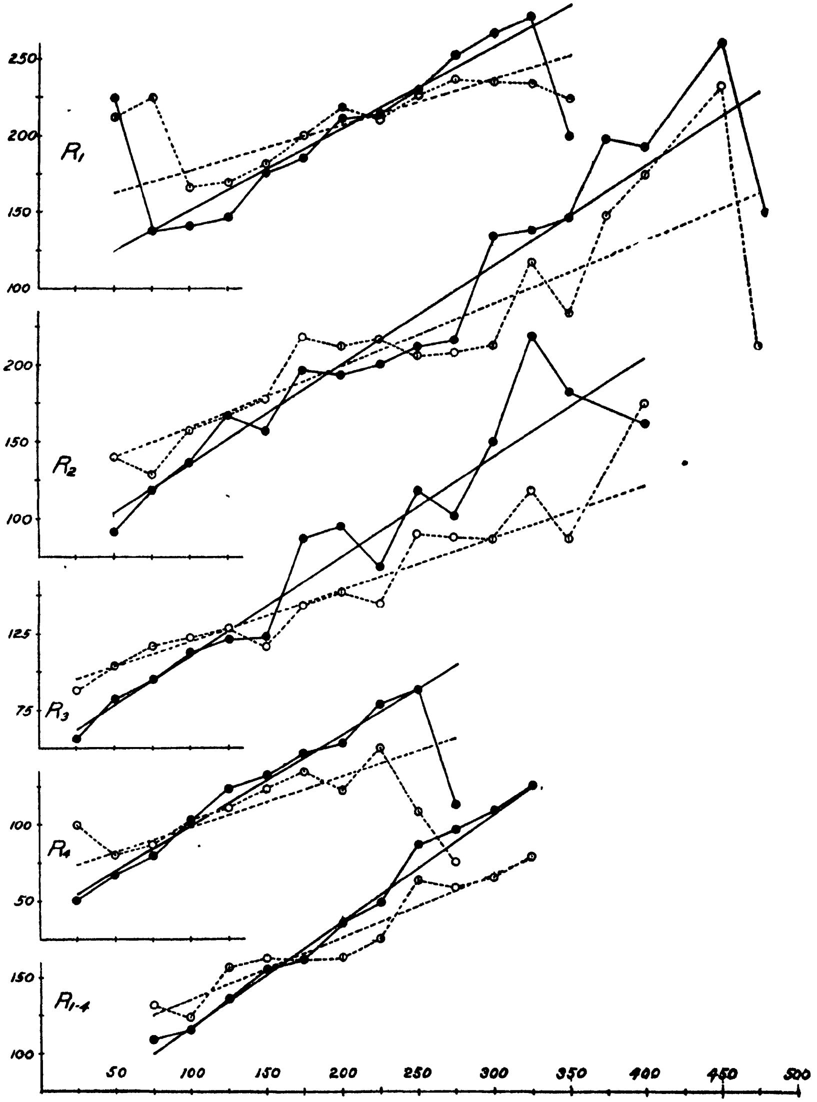

FIG. 6.—Regression of the electrical resistance of the saturated soil mass of associated plats in an experimental field at Sacaton, Arizona. Solid dots and lines represent immediately adjacent plats. Broken circles and broken lines represent plats separated by intervening plats.

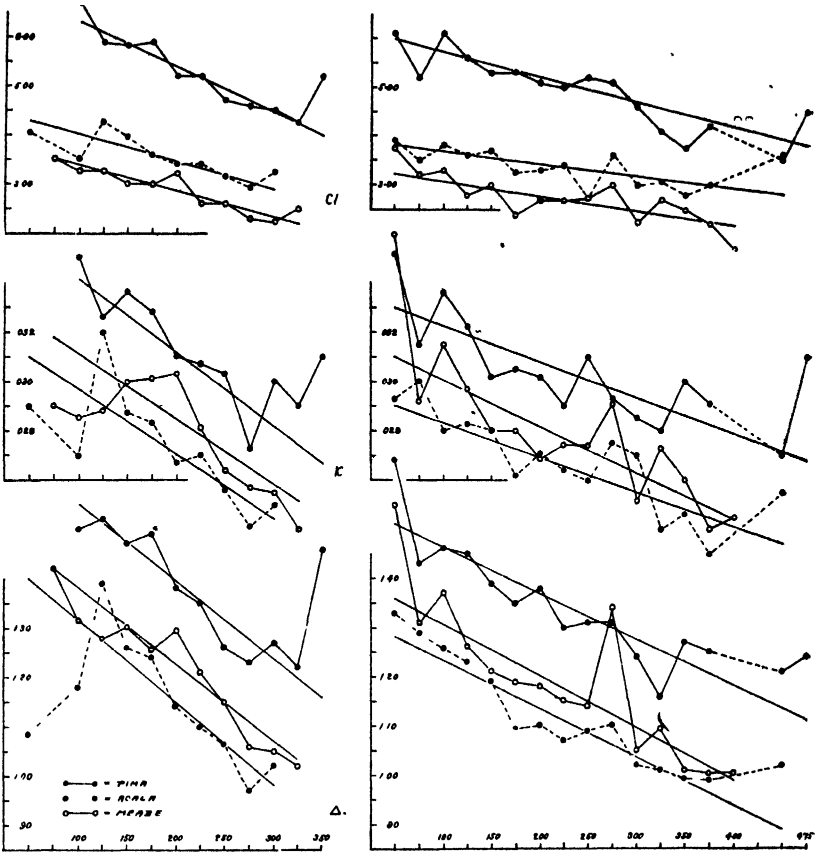

FIG. 7.—Regression of freezing point depression, Δ, specific electrical conductivity, K, and chloride content, Cl, of the leaf tissue fluids of Pima Egyptian and Meade and Acala Upland cotton on the electrical resistance of the soils of the first (left panel) and second (right panel) foot in an experimental field at Sacaton, Arizona.

with an increase in the distance by which the plats are separated,[12] as has been noted for the case of the correlations for individual rows above.

Glancing back over the foregoing constants, it is interesting to note that the coefficients for soil heterogeneity with respect to water content and chemical characteristics are of about the same order of magnitude as those which have been found for crop yields. While this fact does not prove that the observed heterogeneity as expressed in yield is actually due to the heterogeneity of physical or chemical characters of the soil, it establishes a strong presumption that this is the case.

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[12] Since the correlation surfaces have been rendered symmetrical, the correlation coefficient and the regression coefficient are identical. The slope of the lines therefore correctly represents the magnitudes of the two correlations.

CORRELATION BETWEEN THE PROPERTIES OF THE SOIL AND THE CHARACTERISTICS OF THE PLANT

The problem now arises as to whether the very irregularities of the field which have been a source of difficulty in the testing of varieties, or of cultural methods, may not serve as stepping stones to new methods of investigating problems which have heretofore been attacked only by other methods.

In the main, physiologists interested in agriculture have devoted their efforts to the solution of the problem of the relationship between the properties of the soil and the characteristics of the plants largely to attempts to isolate and control experimentally the several variables under consideration. The possibility of taking certain of these investigations into the field will depend upon (a) the possibility of obtaining suitable measures of plant characteristics and soil properties on the basis of field cultures, and upon (b) the existence of such an orderliness of the relations between the properties of the soils of the different parts of the experimental field, on the one hand, and between the properties of the soil and the characteristics of the plant grown upon it, on the other, that the complex nexus of interrelationships may be brought within the grip of mathematical analysis.

In preceding paragraphs the regularity of the relationships between the soil properties and the crop properties of adjacent plats has been amply considered. We now turn to the problem of the direct measurement of the relationship between the properties of the soil and the characteristics of the plant in terms of the correlation coefficient, and to a consideration of the nature of the mathematical function which binds the one to the other.

The intimacy of the correlations (17) between the electrical resistance of the soil and the freezing point depression, specific electrical conductivity, and chloride content of the leaf tissue fluids of the plants may be illustrated by the lines for the regression equations[13] as shown in Fig. 7 for a series of determinations made between August 24 and September 4.

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[13] Since the soil concentrations are expressed in terms of resistance instead of in terms of conductivities (the reciprocals of the resistances), a negative sign indicates that higher osmotic concentrations of the plant tissue fluids are associated with higher concentrations of the salts in the soil. For this reason a descending slope of the regression lines indicates a positive correlation between the concentration of salts in the soil and the concentration of solutes in the plant tissue fluids.

While these figures are drawn primarily to show the relationship between the soil properties and the plant characters, they also indicate the differentiation of the three types of cotton as emphasied elsewhere.

For all these constants the line for Pima Egyptian cotton lies above those for the two Upland cottons (Meade and Acala). For both osmotic concentration, in terms of freezing point depression, and specific electrical conductivity the line for Meade Upland cotton lies above that for Acala Upland cotton, whereas for chloride content the reverse is true. This result suggests differentiation of these two Upland types with respect to their sap properties, to be investigated in greater detail later.

All of these graphs indicate excellent fits of the theoretical lines and the empirical means. While the results have particular applicability to *Gossypium*, they have a two-fold wider significance from the standpoint of methodology. First, they show clearly that the physico-chemical properties of the leaf tissue fluids of the plant may have a measurable, and intimate relationship to the physical and chemical properties of the soil, even when a relatively small area is under consideration They furnish crucial evidence, therefore, that heterogeneity with respect to crop production may be due to heterogeneity with respect to the physical and chemical properties of the field. Second, they indicate that with greater care in cultural detail, with more suitable measures of the characteristics of the soil and the plant organism, and with a proper application of our present knowledge of statistical methods, it should be possible to carry into the field many of the physiological investigations which we are accustomed to think of as amenable only to laboratory experimentation. Series of analyses of soils and of plant tissue fluids are now under way for the purpose of extending the scope of these investigations.

THE INFLUENCE OF PREVIOUS CROPS UPON SUBSEQUENT YIELDS

In many instances the fields which are divided into plats for experiment station work have been previously cultivated, and in many cases devoted in part to different crops. The heterogeneity of our experimental fields may be in part due to diversity of previous agricultural treatment.

A discussion of the problem of the influence of previous crops on subsequent yields involves the whole question of rotation. It is my purpose here merely to indicate the way in which the use of the statistical method may demonstrate that even so slight differences as those in the yields of one and the same crop may influence measurably the yields of subsequent crops grown on the same plats.

For in the Huntley series of plats, which supplied our illustrations for the discussion of the permanence of differences in the plats of an experimental field, it has been shown that the correlations between different yields of alfalfa are higher than those for other crops. This is doubtless due in part to the fact that alfalfa is a perennial, and that differences in the thickness of the stand may be an important factor in determining the inter-annual correlations.

Fortunately, two crops of ear corn were grown on this series of plats following the breaking up of the alfalfa in the fall of 1914. The yields of these two crops have been correlated with each cutting of the three previous years, 1912 to 1914, inclusive, during which the plats stood in alfalfa.

The average values of the various correlations which may be deduced for the two corn series[14] are given in Table 5.

TABLE 5.—*Comparison of correlations between alfalfa yields during 1912, 1913, and 1914 and ear corn yields on the same plats in 1915 and 1916.*

Size of plats	Number of correlations	Average correlation for 1915	Average correlation for 1916
Whole plats	9	+0.1592	+0.7083
Half plats	6	+0.1811	+0.7291
Quarter plats.....	4	+0.1585	+0.6255

The coefficients are conspicuously larger for the second crop than for the first crop of corn following the alfalfa. The agronomic explanation of this result has been discussed by Mr. Scofield and myself in the original paper. There we furnish some evidence for an even more protracted residual influence of the alfalfa yields. Without going into details here, we may note that the points of importance so far as matters of fact are concerned, are, first, that the influence of variations in the yield of a preceding crop may not make itself fully manifest until at least the second year after its removal, and second, that it may persist for a number of years.

VARIETY TESTS AND PLANT BREEDING

The discussion in the foregoing section will, I hope, clear up many points concerning the probable errors of variety tests. There are, however, a number of difficulties due to variations in climatic conditions throughout the period of years over which they were originally conducted. These are now under investigation.

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[14] The correlations for the entire crops of the three years are given in Fig. 4.

CONCLUSION

The foregoing discussion is in itself a summary of progress which has been made during the past 15 years along certain lines of attack on the problem of the interpretation of the results of plat tests. It need not be further condensed so far as detailed results are concerned. Instead, I should like to submit and to comment briefly on four propositions which should now seem so self evident as to be almost axiomatic.

First, increase in our national crop production cannot depend primarily upon a more extensive agriculture. It must depend upon a more intensive agriculture.

Second, continuous refining of the methods of agricultural experimentation are necessary to provide the more precise theoretical knowledge of crop plants which is essential to a more intensive practical agriculture.

Third, many agricultural problems can be solved only by the methods of greenhouse and laboratory experimentation. Other problems can best be solved by the method of plat tests. For this reason, and because of their value for purposes of demonstration, the plat test is destined to play an increasingly rather than a decreasingly important rôle in agronomic research.

Fourth, the cost in public funds and the importance in practical agriculture of the results which may be obtained from plat tests demand that they have the highest possible trustworthiness. This end can be attained in only two ways—increased refinement of experimental technic and increased refinement in the statistical analysis of the results of experimentation.

The present discussion leaves untouched the first of these two possibilities except in so far as it has shown that statistical criteria for the testing of the adequacy of experimental technic are at hand. Its main purpose has been to show that in the second of the two lines of advance towards the goal of greater precision most gratifying progress has been made. In less than two decades we have passed from a period in which practically no use was made of the methods of statistical analysis in the interpretation of plat yields to a period in which varied application of such methods is being made, and in which it is now evident that many problems heretofore considered as soluable only by the methods of laboratory experimentation may be successfully carried on in the field.

While the outlook for the future seems most hopeful, it must not be assumed the goal has been reached. We are, in my opinion, only at the beginning of a satisfactory utilization of the plat test method.

The diversity of purpose, of method, and of data (of the plat tests conducted in the past) usually makes an attempt to compile and interpret the results of earlier experimentation for even a single crop completely baffling. The problem of standardization of method, as well as that of the analysis and presentation of results, must receive most careful consideration before we are in a position to make the best use of the results of this method of experimentation.

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THE NITROGEN AND DRY MATTER CONTENT OF SWEET CLOVER TOPS AND ROOTS AT VARIOUS STAGES OF GROWTH[1]

H. J. SNIDER AND M. A. HEIN[2]

The Illinois Experiment Station as early as 1905 started some field experiments the object of which was, according to a statement in the original records, "to test the value of sweet clover as a leguminous green manure crop." With this beginning sweet clover has been extensively used as a green manure in field experiments and has shown marked success in all sections of the state. These field results have been of immense practical value to the farmer and have given rise to many questions of importance regarding the utilization of sweet clover for various purposes. One important question is that pertaining to the fertility value of the tops and roots at various stages of growth. This paper deals especially with the nitrogen and dry matter content of tops and roots at various stages during the growth of the sweet clover plant.

EXPERIMENTAL

The data reported in this paper were obtained from sweet clover grown on the Spring Valley experiment field which is located in the

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The writers wish to express their appreciation to Dr. A. L. Whiting and Dr. F. C. Bauer for suggestions in carrying out this work and preparing this paper.

[2] Assistant Chief and Associate in Experiment Fields, respectively.

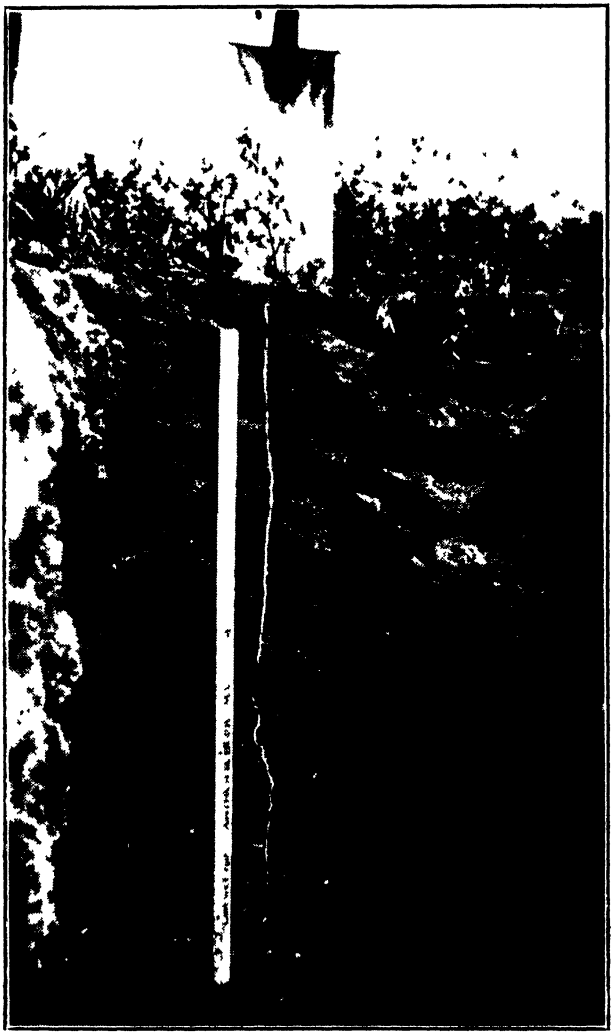

FIG. 1.—Sweet clover root exposed previous to removal from the soil. Measuring stick, 36 inches in length.

northern Illinois corn belt. The soil on this field, according to the Illinois classification, is the brown silt loam type, and the particular area from which the sweet clover samples were taken is rather deep and fertile The subsoil is of such a nature that the sweet clover roots penetrate it very readily, developing a single tap root system with little or no branching, as shown in Fig. 1. Ground limestone was applied to this land in 1915.

The sweet clover used in this investigation was the common white-blossomed biennial (*Meliotus alba*). This was seeded with Sixty-day oats in March or April at the rate of approximately 10 pounds of seed per acre. The oats were seeded at the uniform rate of 8 pecks per acre. They were allowed to mature and were harvested in the regular manner. The sampling was not begun until the sweet clover had made some growth after the oats were removed. The nodule development was profuse, especially in the first 7 inches of soil. Some nodules were found at a depth of 40 inches.

The sweet clover at each sampling was removed from a 4-square-foot area (2 ft. x 2 ft.), and all roots were taken to a depth of 40 inches. The roots were divided with regard to their distribution in the three strata of soil as indicated in the tables. Some of the roots did not penetrate to the 40-inch depth, while some went beyond this depth. The samples of tops included only the current season's growth, except in some early spring samples the old growth of the previous season was collected. Acre weights and percentage of nitrogen were determined as shown in Table 5.

The nitrogen determinations were made and are reported on the water-free basis, while the dry matter weights are reported on the air-dry basis. The pounds per acre of total nitrogen reported in Tables 3, 4, and 5 are not absolute but only approximate. They should be considered, therefore, as only relative for the various stages of growth represented by the samples taken. The percentage nitrogen reported in Table 1 and the dry matter weights in Table 3 were secured from sweet clover which was seeded with oats, April 29, 1922, and the sampling continued at intervals from September 11 to December 28. The following spring sampling of the second season's growth was begun March 30 and continued at intervals to July 16, at which time the sweet clover had reached maturity.

The percentage nitrogen and dry matter weights reported in Tables 2 and 4, respectively, were secured from separate seedings of sweet clover. The data reported for 1923 were obtained from sweet clover seeded with oats April 5, 1923, and sampled at intervals from August 8 to November 16 of that year. The data reported for 1922 in these tables were obtained from sweet clover seeded with oats March 31, 1921, and sampled at intervals from March 24 to June 27, 1922.

In Tables 1, 2, 3, and 4 there are no data recorded under dry matter for tops for several dates during March and April. This may be explained by the fact that there was no new growth present

TABLE 1.—*Percentage of nitrogen found in sweet clover tops and roots at various dates.*

Date sampled	Tops	Roots	
	%	0" to 7" %	7" to 40" %
1922			
Sept. 11	3.60	3.52	3.99
Sept. 20	3.14	4.00	3.82
Sept. 27	3.28	3.49	3.40
Nov. 2	1.93	4.03	3.51
Nov. 9	1.85	4.24	3.65
Dec. 28	1.46	4.50	3.83
1923			
March 30	—	5.23	4.37
April 5	—	4.56	4.60
April 13	–	5.06	3.72
April 19	4.70	5.06	4.33
April 30	5.82	5.50	4.87
May 8	4.85	4.18	3.69
May 17	4.19	3.52	3.10
May 25	3.72	2.91	3.25
June 14	2.86	2.23	1.99
June 22	3.36	2.40	2.25
June 30	2.34	2.25	2.09
July 6	2.23	2.39	1.83
July 16	2.04	2.19	1.76

TABLE 2.—*Percentage of nitrogen found in sweet clover tops and roots at various dates.*

Date sampled	Tops	Roots	
	%	0" to 7" %	7" to 40" %
1923			
Aug. 8	3.41	2.51	2.51
Aug. 31	3.34	2.69	2.69
Sept. 11	3.59	2.82	2.85
Oct. 26	3.00	3.62	3.19
Nov. 9	2.67	3.48	2.85
Nov. 16	2.31	3.96	3.13
1922			
March 24	—	4.90	4.11
April 5	6.12	4.76	4.14
April 20	6.81	4.75	3.73
April 28	4.71	4.60	3.60
May 8	5.50	3.36	3.25
May 13	4.14	—[a]	2.96
May 20	3.47	3.58	2.83
May 30	3.12	—[a]	2.91
June 7	2.82	2.96	2.12
June 13	2.48	—[a]	2.12
June 19	2.19	2.05	2.23
June 27	1.96	—[a]	1.64

[a] Sample lost.

TABLE 3.—*Pounds per acre of air-dry sweet clover tops and roots and total nitrogen content at various dates in the life of the plant.*

Date	Tops		Roots		Total	Total	Total
sampled		0″ to 7″	7″ to 20″	20″ to 40″	roots	plant	nitrogen
1922							
Sept. 11	2,850	700	440	100	1,240	4,090	150
Sept. 20	3,420	1,840	620	180	2,640	6,060	212
Sept. 27	4,280	2,150	670	100	2,920	7,200	241
Nov. 2	3,130	3,580	1,110	190	4,880	8,010	250
Nov. 9	3,350	4,130	890	180	5,200	8,550	276
Dec. 28	1,870	4,140	670	130	4,940	6,810	244
1923							
Mar 30	——	3,460	970	190	4,620	4,620	232
Apr. 5	– —	3,410	640	190	4,240	4,240	183
Apr. 13	——	3,490	950	240	4,680	4,680	211
Apr. 19	510	4,120	1,100	290	5,510	6,020	292
Apr. 30	1,320	2,030	560	170	2,760	4,080	225
May 8	2,230	1,920	400	140	2,460	4,690	208
May 17	2,320	1,230	190	60	1,480	3,800	148
May 25	3,330	1,310	310	120	1,740	5,070	176
June 14	5,060	1,330	270	120	1,720	6,780	182
June 22	5,870	1,230	250	50	1,530	7,400	234
June 30	6,970	1,510	370	70	1,950	8,920	206
July 6	6,700	1,110	230	60	1,400	8,100	181
July 16	7,310	1,140	220	70	1,430	8,740	179

TABLE 4.—*Pounds per acre of air-dry sweet clover tops and roots and total nitrogen content at various dates in the life of the plant.*

Date	Tops		Roots		Total	Total	Total
sampled		0″–7″	7″–20″	20″–40″	roots	plant	nitrogen
1923							
Aug. 8	380	110	20	10	140	520	17
Aug. 31	1,240	670	190	70	930	2,170	66
Sept. 11	1,040	560	100	40	700	1,740	57
Oct. 26	1,510	2,110	540	170	2,820	4,340	144
Nov. 9	1,830	2,680	540	170	3,390	5,220	162
Nov. 16	1,320	3,160	650	160	3,970	5,290	180
1922							
Mar. 24	——	2,740	540	160	3,440	3,440	163
Apr. 5	120	2,430	460	110	3,000	3,120	147
Apr. 20	520	1,600	560	170	2,330	2,850	135
Apr. 28	1,440	1,810	430	120	2,360	3,800	171
May 8	970	1,060	210	100	1,370	2,340	99
May 13	2,180	1,860	880	240	2,980	5,160	188
May 20	4,210	2,560	450	230	3,240	7,450	257
May 30	5,200	1,730	380	80	2,190	7,390	232
June 7	10,280	2,620	400	200	3,220	13,500	381
June 13	6,930	1,920	340	80	2,340	9,270	225
June 19	12,010	1,700	340	120	2,160	14,170	308
June 27	9,050	1,440	190	50	1,680	10,730	211

TABLE 5.—*Nitrogen and dry matter found in sweet clover tops representing summer and fall growth collected the following spring.*

Date sampled	Nitrogen %	Dry matter, pounds per acre	Nitrogen, pounds per acre
1922			
March 24	1.51	1,620	24.5
April 5	1.21	1,640	20.8
1923			
March 30	1.11	1,460	16.2
April 5	1.18	950	11.2

at these dates of sampling, and the old top growth of the previous season is reported in part in Table 5. The dry matter reported in Table 5 does not include that of the sweet clover leaves which were lost from the plant during the fall and winter season.

It is apparent that the acre weights of sweet clover here reported are only approximate and not absolute. There may be discrepancies due to the small area sampled at each date, to the variation of individual plants, to the variability of the sweet clover stand, and to seasonal peculiarities. Inaccuracy due to these causes, however, may be overcome to some extent by the large number of samples collected over a period of two years.

DISCUSSION OF RESULTS

The data presented in Tables 1 and 2 indicate that during the autumn months as the plant enters dormancy the nitrogen content of the tops decreased while that of the roots increased. The plant as a whole contained the highest percentage of nitrogen at about the time the second season's top growth was well started in early spring. In this investigation, the highest percentage of nitrogen was found in April of the second season as may be seen in Fig. 2. The percentage of nitrogen in both roots and tops decreased from this high point as the plant approached its maximum growth and maturity (Fig. 2).

During the growing stages, the tops apparently contained a higher percentage of nitrogen than did the roots. The portion of the root in the surface strata of soil (0 to 7 inches) contained, as a rule, a higher percentage of nitrogen than did the portion in the adjoining lower strata of soil (7 inches to 40 inches).

The data presented in Tables 3 and 4 indicate that on this type of soil the root growth develops its maximum in depth and bulk during the summer and fall of the first season's growth of the plant. These data show that by far the largest bulk of the root was in the first 7 inches of soil. There was, however, a considerable portion of root development between the 7-inch and 20-inch strata,

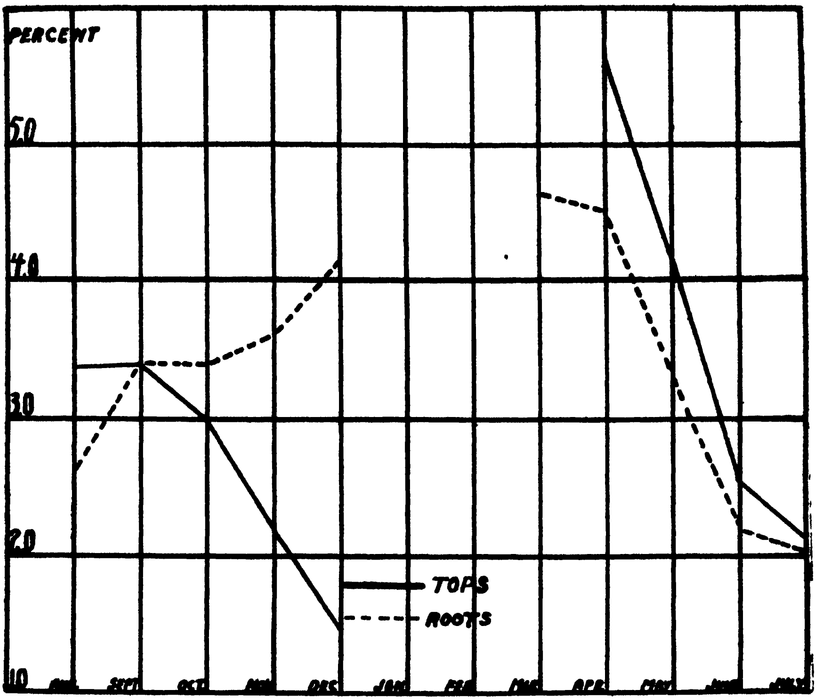

FIG. 2.—Percentage nitrogen found in sweet clover tops and roots as a two-year average.

and an appreciable amount between the 20-inch and 40-inch depth. The maximum top development, as well as the total maximum dry matter content, was reached in June and July of the second year's growth.

These results show that sweet clover contains a relatively large amount of nitrogen per acre. The results for the two years averaged by months, as presented in Tables 3 and 4, indicate that for November, March, April, and May the nitrogen per acre was close to 200 pounds for each of these months. During the months of November, March, and April, the greater part of the nitrogen contained in the sweet clover was below the surface of the soil. The largest total amount of nitrogen found in the sweet clover crop was during the month of June, and during this month the two-year average was approximately 240 pounds per acre. The larger portion of this, however, was contained in the heavy top growth which reaches its maximum during June and July.

From the practical standpoint this investigation shows that common biennial sweet clover seeded in small grain crops may, after the small grain is harvested, make a rather heavy top and root growth before the plant enters dormancy. It is apparent that this top growth may give a fair yield of fall hay or supply a certain amount of late summer and early fall pasture. The results further indicate that as a green manure sweet clover may be plowed under in the early spring of its second year's growth and supply a large amount of available nitrogen, thus establishing a most favorable condition for corn or other crops requiring large amounts of this element in readily assimilable form.

SUMMARY

When seeded in small grain crops in the spring, biennial white-blossom sweet clover developed during the summer, fall, and following spring a large amount of organic matter in both roots and tops.

The roots reached their maximum development both in depth and bulk during the fall of the first season's growth, while the tops reached their maximum in bulk when the plant reached maturity during the following summer.

The sweet clover developed near its maximum in total nitrogen per acre during the fall of its first season's growth, and this remained practically the same during the early part of the following spring.

A two-year monthly average indicates that the sweet clover contained at maturity the maximum amount of nitrogen per acre, which was largely contained in the coarse heavy top growth.

The highest percentage of nitrogen was contained in the roots during the fall and winter, while in the spring and summer growth the tops contained the highest percentage of nitrogen.

The dry matter and nitrogen carried over winter in the summer and fall top growth of the first season is worthy of consideration from a fertility standpoint.

EFFECT ON NODULATION OF SUPPLEMENTING THE LEGUME BACTERIA OF THE SOIL WITH ARTIFICIAL CULTURES[1]

J. K. WILSON[2]

Abundant nodule formation on legumes under field conditions is dependent on several factors. One of these is the proper number of nodule-producing organisms. Since nodule production on plants is the result of chance contact, there should be a rather large number of the legume bacteria present in the soil in order that maximum nodulation may occur. The practical and scientific point in this connection is whether or not the soil will maintain under various cropping conditions from year to year or longer the legume bacteria in sufficient numbers to meet the requirements of the young plants. One finds in the literature conflicting evidence concerning this point.

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[1] Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication February 2, 1926.

[2] Professor of Soil Technology.

Pieters' (8)[3] is of the opinion that there is no experimental evidence to support the frequently suggested idea that one cause of clover failure in acid soils is the absence of the proper legume bacteria. He assumes that the absence of the proper organisms is not the cause of failure, because when alsike clover was grown on those soils where red clover had failed there was an abundance of nodules.

Deherain (5), 25 years ago, in studying the distribution of bacteria throughout the soil, made comparisons between soils variously fertilized and cropped with vetch for the presence of the legume organism. He found an abundance of nodules on plants, although no legumes had been grown on the soil for 25 years. He believed, however, that abundance of bacteria may be carried by the wind, etc., to all soils and that artificial cultures are unnecessary.

The effect of desiccation on the viable legume bacteria in soil was studied by Albrecht (1). He found that the legume bacteria was effective for inoculating purposes whether the soil containing it was dried in the absence or in the presence of direct sunlight, and that the dried soil stored for 30 months was as good for inoculating purposes as the fresh soil gathered from the field. He also made certain tests in which nodule production was a basis for his conclusions, the results of which were believed to indicate that soils once inoculated for soybeans and red clover will not need to be reinoculated when these crops recur in a four-year rotation. The number of nodules per plant that appeared on the roots in soils that had been previously sun-dried, however, was less than that observed in earlier tests.

Many more articles may be found in the literature to substantiate the opinion that once the soil has been inoculated with the legume organism the normal development of the organism in the soil will suffice for future crops. Whiting (9), however, presents evidence to show that in certain soils this may not be the case. He obtained data from plants grown in an acid silt loam soil of medium fertility that had grown peas 11 years previously. These data showed an improvement in the growth of peas when the natural legume bacteria was supplemented with artificial cultures. On examining plants from the inoculated portion every one had nodules, while on that part of the field where the plants were dependent on the legume bacteria which the soil normally supported nodules were present on some plants. Other benefits of supplementing the legume bacteria of the soil were higher vines, greater yield of vines and protein content, and a larger percentage of No. 1 and No. 2 grades of peas.

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[3] Reference by number is to "Literature Cited," p. 294.

Hiltner (6) maintained that the kind of treatment a soil received would, in a measure, determine the group of legume bacteria that would survive. He believed that liming the soil either injured or rendered inactive the lupine bacteria.

One may conclude from the investigations cited that certain soils may contain a sufficiently high legume bacteria content to supply the needs of the new crop, while others may not. In case they do not, augmenting the flora already present with artificial cultures should tend to increase the number of nodules found on the plants. The effect in turn should be reflected in a thicker stand, in greater nitrogen content of the plants, and in general vigorous appearance. It is hoped that the following experimental evidence will throw some light not only upon the value of supplementing the supply of legume bacteria in the soil with artificial cultures but also upon the longevity of the organism in soil variously fertilized and cropped.

METHODS

Attempts have been made by various investigators to determine the number of legume organisms in the soil. Joshi (7) used a medium that was designed to exclude growth of most organisms except those that produce nodules on legumes. Greig-Smith tried the same procedure. This line of attack has not given entire satisfaction. Even if this method of determining the number of legume bacteria in the soil showed what it was designed to show, it would not tell what groups of the organism were present. Since one effect of the organism in soil is to induce nodule formation on legumes, it becomes important to know if the organism is present in the soil in sufficient numbers to effect maximum nodule production.

A brief statement of the procedure that has been used by the writer in obtaining such information may be given. Samples of soil were collected from plats the fertilization treatments and crop histories of which were known for a number of years. They had been in most cases inoculated at time of seeding with an artificial culture. If they had not been inoculated at time of seeding, it was believed that the proper bacteria were once present, for the plats had either grown the host plants successfully or had been exposed to the organism by the farming operations. These samples were used as a medium in which nodule production for each group of the legume bacteria might be studied. One part of the soil was used without the addition of more bacteria, while the other had the organism added to it. The value of this supplementary treatment was measured by counting the visible nodules on the plants.

SAMPLES AND METHOD OF HANDLING

Implements that were known not to have the legume organism on them were used in obtaining the samples. Borings were made at a number of places on a plat. The soil, which was thus collected, was made into a composite sample. From this sample equal weights of the soil were placed in glass tumblers. The soil and tumbler were weighed in order that the moisture content of the soil could be controlled. The loss in moisture was replaced daily by the addition of distilled water. This was deemed necessary for the writer (10) has shown that for soybeans a variation in the soil moisture results in an uneven nodule production. The amount of soil used in the tumblers varied somewhat but an average was about 250 grams. Also 100-gram portions were used in moisture determinations.

SUPPLEMENTING THE INOCULATION

In making comparisons of the value of additional legume bacteria soil was added to each of two tumblers. The soil in one received no treatment other than distilled water. The soil in the other was inoculated with the desired legume bacteria. This was accomplished by taking an active culture of the organism and mixing it with the distilled water that was used to bring the soil to proper moisture content for the growth of the host plant. In no case, however, was the soil allowed to become drier than was necessary for good handling. Seeds were planted in both soils and shortly after they were placed in the greenhouse. Previous tests had determined the number of days required before good nodules may be expected. At the end of this period, which varied with different host plants, nodules were counted.

DETERMINING NODULES

When it was believed that the plants had developed sufficiently so that nodules might be macroscopically recognized, the plant roots were washed free of soil and each examined carefully. Uneven germination of the seeds resulted in plants of several days, difference in age. The younger plants were easily recognized, however, and were removed before counting was begun. No systematic attempt was made to grow the same number of plants in each soil, although the seeding was approximately the same.

DETERMINATION OF SOIL REACTION

It was thought that a study of the reaction of the soil in connection with the presence or absence of the legume organism might help to explain the data which are here reported. Two methods, therefore, have been employed to this end. The soil in one case was extracted with two and one-half times its own weight of water and the extract centrifuged Indicators were added to small portions of the clear or opalescent solution thus obtained. The final color which developed was compared with a pH chart and the reaction noted.

In the other case, 5 grams of moisture-free soil in a test tube received 7 cc. of the potassium thiocyanate solution recommended by Comber (4) for the detection of acid or alkaline soil. This test enabled one to judge how acid a soil sample was in comparison with other samples and proved very useful in this way. With possibly one exception the two methods were in accord as regards the soil reaction. This possible exception was due in all probability to failure in securing a clear extract before adding the indicator.

EXPERIMENTAL

In making this study evidence was sought concerning those groups of bacteria which produce nodules on the leguminous crops commonly grown in New York. Based upon trials made by a number of investigators, the nodule organisms have been divided into ten or more groups according as they are interchangeable for the purposes of inoculation. Results of only four of these groups are reported in this paper. One group contains the organism for *Pisum* and for *Vicia*, another for *Trifolium*, another for *Medicago* and *Melilotus*, and the fourth for *Sojas max* Piper.

EXPERIMENTS WITH VICIA

In determining the value of supplementary legume bacteria in the soil, as measured by increased nodules on the plants, vetch seed (*Vicia sativa*) were sown in soil from seven different plats on November 16, as described previously. On December 2, the resulting plantlets were washed free of soil and the number of nodules counted. The results of the counts, together with other data, are given in Table 1.

It can be seen easily from the table that in certain cases there was no benefit derived from augmenting the legume bacteria with artificial culture, while in other cases there was a decided increase in nodule production. In each case where there was no increase in

TABLE 1.—*Effect on nodulation of supplementing the nodule organism of the soil with an artificial culture for vetch.*

Plat No.	Pounds of limestone applied per acre since 1910	Years in vetch or peas	pH	Number of nodules on each plant		Average number of nodules per plant	
				Uninoculated	Inoculated	Uninoculated	Inoculated
758	4,000	1917 to 1925	6.7	4, 2, 5, 5, 3, 7, 3, 6, 5, 8, 7, 8, 3, 1, 5, 1, 3	5, 4, 9, 2, 6, 2, 4, 5, 9, 4, 4. 5, 4, 8, 6, 4	4.47	5.06
761	None[a]	1917 to 1925	5.4	3, 4, 0, 0, 3, 3, 0, 2	6, 3, 6, 8, 5, 4, 3 6, 4, 5, 6, 3	1.87	5.00
2201	3,000	1925	6.2	9, 7, 8, 8, 10, 1, 7, 6. 7, 10, 5, 8, 9, 11, 10	6, 7, 6, 12, 5, 5, 6, 7, 9, 8, 6, 9, 6, 4, 6, 7	7.66	6.81
7005	None[a]	1916 1921	5.6	1, 4, 3, 3, 4, 0, 0, 0, 2, 1, 1, 2, 1, 2	5, 5, 7, 4, 11, 4, 6, 5, 7, 3, 4	1.71	5.55
7006	None[a]	None[a]	5.6	0, 0, 0, 1, 0, 0, 0, 0, 0, 0 0, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	3, 5, 6, 8, 5, 9, 4 4, 7, 8, 3, 5, 8	0.08	5.77
7011	9,000[b]	1916 1921	6.8	3, 4, 7, 2, 1, 4, 2, 1, 5, 0, 7, 1, 5, 6, 6, 9, 3, 4, 10, 2, 6, 5	4, 4, 8, 3, 3, 5, 8, 6, 5, 7, 6, 7, 4. 6, 7. 3	4.43	5.38

[a] History of soil previous to 1910 unknown.
[b] As burned lime.

nodulation limestone had been added to the soil from time to time and the soil reaction showed pH 6.2 or greater. In all other cases nodule production had been increased by the addition to the soil of more legume bacteria. Plat 758, which has received 4,000 pounds of limestone since 1910, has grown vetch as a cover crop nine years. Vetch plants grown in artificially inoculated soil from this plat showed an average difference of less than one nodule per plant over those found on plants grown without inoculation. Plat 761, which has no liming record, was also used for vetch as a cover crop nine years. Vetch plants grown in artificially inoculated soil from this plat showed an average difference of more than three nodules per plant over those found on plants grown without the artificial culture.

These data are taken to indicate that the soil of plat 758 contains an ample supply of the legume bacteria for the plants, while that of plat 761 fails to support a legume bacteria content in sufficient numbers to allow maximum nodulation on the young plants.

The data in Table 1 also show a direct correlation between nodule production and the reaction of the soil. In addition to the pH figures given in the table all the soils were tested for their need of lime by the Comber (4) method All were tested at the same time and the soils lined up from the faintest to the strongest color. This gave the following order: Plats 7011, 758, 2201, 761, 7005, and 7006. This is a perfect correlation with decreasing nodule production, with the exception of where lime has been applied, the more pronounced the color the fewer the nodules per plant to be expected.

It is interesting to note in Table 1 that some of the plants that grew in the uninoculated soil had no nodules, while every plant that grew in the inoculated soil had one or more nodules. This would suggest that the legume bacteria were unevenly distributed in the soil.

Plat 7006, so far as is know, has never grown vetch or peas. The plats on either side of it grew peas in 1916 and 1921. The apparently few legume bacteria in this soil would suggest that either the bacteria suitable for this particular crop is not easily carried from plat to plat by ordinary farming practices or that this particular plat is not a favorable habitat for the legume bacteria of *Vicia* and *Pisum*.

EXPERIMENTS WITH TRIFOLIUM PRATENSE

The growth of *T. pratense* in soils and its gradual disappearance from them has been observed by many agriculturists. Such soils have often been described as clover-sick soils. The question often asked about this soil is, do the bacteria which produce nodules on clovers also simultaneously disappear from the soil? Little evidence is available on this point.

Tests with this plant have been made in a similar way as were tests for the value of supplementary bacteria in the form of artificial cultures for *Pisum* and *Vicia*. Samples were collected from 11 plats representing a wide range of crop rotation and fertilizer treatments. On November 16 seeds of *T. pratense* were planted, and on December 8 the young plantlets were washed free of soil. The results of nodule count, together with other data, are given in Table 2.

These data show that certain plats maintain a large enough legume bacteria content for maximum nodulation on *T. pratense*. The results from plats 729, 758, 1014, 1638, 2001, 5733, and 7011 show practically no benefit, as measured by increased number of nodules, from adding more legume bacteria to the soil. With the exception of soil from plat 729 all of them have a reaction of pH 6.1 or greater.

Plat 7006 grew grass from 1910 to 1919 and was kept bare from 1920 to time of sampling. The increased nodulation due to supplementary legume bacteria for *T. pratense* in the soil of this plat is very marked. Plat 1014 grew a luxuriant crop of *T. pratense* in 1925 and the data show no effect on nodule production from augmenting the legume bacteria for this plat.

Certain other soils show increased nodulation by augmenting the nodule bacteria in the soil. The results from plats 761, 3605, and 7006 bring out this point very closely. Also, it is noted that the soil from these plats has a reaction of pH 5.6 or less.

Plats 758 and 761 have not grown *T. pratense* since 1910. Their history before this time is unknown. Since the soil from plat 758 has a reaction of pH 6.7 and shows no benefit from supplementary legume bacteria, while that from plat 761 has a reaction of pH 5.4 and responds to supplementary bacteria, it would seem that the pH of the soil may be a limiting factor in nodule production.

Since a few visible nodules were produced on *Trifolium* plants grown in soil with a pH 5.4, while many were produced in soil from the same field that had a pH 6.2, it suggests that possibly the bacteria may be abundantly present in the very acid soil but that they are not able under this very acid condition to effect maximum nodulation.

Bewley and Hutchinson (3) have suggested that a definitely acid soil may render inactive or perhaps kill certain legume bacteria. If such an acid soil, therefore, were limed in such a way as to adjust its reaction toward the neutral point, there should be increased nodulation on the plants without the addition of more legume bacteria.

TABLE 2.—*Effect on nodulation of supplementing the nodule organism of the soil with an artificial culture for Trifolium pratense.*

Plat No.	Pounds of limestone applied per acre since 1910	Years in *Trifolium*	pH	Number of nodules on each plant		Average number of nodules per plant	
				Uninoculated	Inoculated	Uninoculated	Inoculated
729	None[a]	—[e]	5.4	0, 4, 1, 2, 2, 3, 2, 3, 3, 3, 1, 4, 1, 3, 3, 2, 1, 1, 3, 0, 2, 3, 2, 2, 4, 3, 2	4, 2, 3, 1, 5, 3, 1, 2, 1, 2, 5, 3, 2, 1, 2, 3, 3, 2, 2, 3, 2, 2, 3, 2, 1, 2, 3	2.22	2.40
758	4,000	—[f]	6.7	1, 4, 3, 3, 2, 2, 1, 3, 2, 2, 2, 2, 2, 1, 3, 3, 1, 2, 3, 1, 2, 2, 2, 1, 3	3, 4, 3, 2, 2, 2, 2, 3, 2, 2, 4, 3, 4, 4, 3, 2, 2, 2, 2, 2, 5, 4, 2, 2, 3	2.08	2.76
761	None[a]	—[f]	5.4	0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 1, 0, 0, 0	1, 1, 2, 2, 2, 2, 4, 2, 1, 2, 4, 3, 1, 2, 1, 2, 1, 1, 2, 2, 1, 1, 2, 1, 2	0.08	1.88
1014	None[a]	1925	6 1	2, 1, 2, 1, 3, 4, 3, 1, 2, 1, 4, 4, 1, 2, 4, 3, 4, 1, 1, 4, 2, 2, 4, 2, 3, 2, 1	4, 3, 1, 1, 2, 4, 1, 3, 3, 2, 3, 2, 1, 3, 2, 5, 5, 4, 1, 5, 1, 1, 3, 3, 2, 2, 3	2.37	2.60
1638	6,000	1921 1925	6.5	3, 3, 3, 2, 4, 1, 4, 2, 2, 3, 3, 2, 2, 2, 3, 1, 1, 1, 2, 1, 1, 3, 3, 3, 2	2, 3, 3, 3, 1, 3, 2, 3, 4, 4, 3, 1, 2, 2, 2, 1, 1, 2, 3, 4, 1, 2, 4, 4, 2	2.28	2.48
2001	12,000	—[f]	6.7	1, 3, 1, 4, 1, 2, 2, 2, 2, 3, 3, 3, 4, 3, 3, 2, 1, 4, 2, 2, 2, 3, 2, 2, 2	1, 3, 2, 2, 2, 2, 2, 2, 1, 2, 2, 2, 2, 1, 2, 4, 3, 2, 1, 5, 2, 2, 2, 3, 5	2.36	2.28
				2, 1, 2, 1, 4, 1, 0, 1, 2, 1, 1, 1, 2, 3,	3, 2, 3, 3, 3, 3, 3, 2, 4, 1, 4, 4,		

3605	None[b]	1922	5.4	2, 1, 2, 1, 2, 0, 3, 0, 1, 0, 1, 2, 2, 0, 2	3, 5, 2, 4, 1, 3, 2, 1, 2, 4	1.41	2.82
5733	5,500	——[g]	6.4	2, 3, 4, 2, 4, 2, 2, 3, 4, 2, 2, 2, 3, 2, 3, 3, 5, 3, 2, 2, 1, 4, 1, 3, 2	5, 2, 3, 3, 2, 1, 3, 2, 3, 3, 3, 4, 2, 3, 2, 1, 1, 1, 4, 3, 2, 3, 2, 3, 3, 3	2.62	2.58
7005	None[a]	1913 1918–19 1923[h]	5.6	3, 4, 1, 3, 2, 2, 1, 2, 2, 2, 1, 4, 2, 3, 2, 1, 2, 2, 1, 1, 2, 1, 1, 1, 1, 3, 1, 1, 2, 2	3, 2, 3, 5, 2, 2, 6, 2, 8, 2, 4, 4, 4, 3, 5, 3, 3, 5, 3, 3, 4, 3, 3, 2, 5, 3, 3, 4, 2, 3	1.86	3.46
7006	None[c]	——[i]	5.6	2, 1, 1, 1, 2, 1, 1, 0, 2, 1, 1, 1, 1, 0, 0, 2, 1, 1, 1, 0, 1, 1, 1, 0, 1	3, 3, 5, 2, 5, 4, 3, 2, 4, 4, 6, 1, 5, 7, 6, 5, 5, 2, 3, 4, 5, 4, 4, 4, 3	0.96	3.96
7011	6,000[d]	1919 and 1923[h]	6.8	3, 4, 3, 2, 3, 2, 2, 1, 4, 4, 4, 4, 3, 4, 5, 5, 2, 2, 1, 1, 1, 2, 2, 2, 3	2, 4, 3, 4, 3, 3, 3, 4, 3, 4, 3, 2, 3, 2, 3, 4, 1, 2, 1, 3, 3, 2, 1, 3, 3	2.76	2.80

[a] History of soil previous to 1910 unknown.
[b] 6 tons manure per acre in 1918.
[c] 10 tons manure per acre in 1910 and again in 1918.
[d] Applied as CaO.
[e] In rotation of wheat, timothy 3 years, corn, and oats.
[f] Not at all unless before 1910.
[g] Hay 1914 to 1915 and 1919 to 1922 in which was volunteer clover.
[h] In 1924 and 1925 plat was in timothy in which was volunteer clover.
[i] Grass 1916 to 1918, bare 1919 to 1925.

In testing this point soil was secured from plat 755. Its reaction was pH 5.4. No crop of *Trifolium* had grown on the soil for at least 15 years, although many plats lying near this one had been allowed to grow red clover quite regularly. Preliminary tests with soil from this plat showed that it probably contained a few bacteria capable of producing nodules on red clover. Also, previous tests in which lime was applied indicated that this treatment may result in greater nodulation.

One portion of this soil served as the neutral soil. Another was limed with about 0.1% calcium carbonate. The third portion was inoculated with a pure culture but received no lime. Seeds of *T. pratense* were planted in the soil in all three cases. After 14 days nodulation was determined.

No nodules were visible on 25 plants grown in the natural soil. Neither were any observed on the plant roots from the soil which had 0.1% calcium carbonate added to it. An average of 2.08 nodules per plant, however, were found on plants grown with supplementary bacteria. From these data it was concluded that the legume bacteria for red clover have ceased to exist in this soil in sufficient numbers to supply the immediate needs of the plantlets. Also, that liming the soil at time of planting did not result in the development of a sufficient legume bacteria content to meet the needs of the plants in their seedling stage.

This relation of soil reaction and increased nodulation on plants by augmenting the proper legume bacteria follows very closely not only the pH of the soil but also the intensity of color developed in the Comber (4) test. Soils were tested for need of lime and arranged in order from no color to the one with deepest color. When this arrangement was set opposite the figure which represents the need of the soils for more bacteria, together with the pH of the respective plat, the soils lined up as follows.

Position of plats in Comber test, no color to deepest color	pH	Order with respect to least need for bacteria
7011	6.8	3
758	6.7	7
2001	6.7	1
1638	6.5	5
5733	6.4	2
1014	6.1	6
729	5.4	4
761	5.4	10
3605	5.4	8
7005	5.6	9
7006	5.6	11

TABLE 3.—*Effect on nodulation of supplementing the legume bacteria content of the soil with an artificial culture for alfalfa (Medicago sativa).*

Plat No.	Pounds of lime since 1910	Years in alfalfa	pH	Number of nodules on each plant		Average number of nodules per plant	
				Uninoculated	Inoculated	Uninoculated	Inoculated
A	None[a]	— to 1913[a]	?	1, 4, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0	3, 3, 2, 3, 6, 3, 2, 4, 2, 1, 1, 4, 5, 4, 4,	0.02	3.13
B	None[a]	— to 1913[a]	5.8	20 good plants, no nodules	2, 1, 1, 4, 1, 3, 2, 1, 2, 1, 1, 3, 1, 2, 1	0.00	1.73
758	4,000	1905 to 1911	6.7	2, 0, 0, 0, 0, 0, 0, 0, 0, 0	3, 2, 1	0.02	2.00
761	None	1905 to 1911	5.8	Plants failed to grow	Plants failed to grow	—	—
1201	22,000[b]	1914–15 1918–21	6.7	1, 1, 1, 2, 1, 1	1, 1, 2, 1	1.16	1.50
1229	9,000[c]	—[d]	6.5	3 3, 1, 1, 1, 1	2, 5, 1, 1, 1, 1, 3	1.66	2.00
2005	15,000	1917–19 1922–24	6.8	2, 1, 1, 1, 1, 2	2, 1, 1, 1, 2, 1	1.33	1.33
3004	6,000	1912–13	5.8	Plants failed to grow	Plants failed to grow	—	—
7533	5,500	—[d]	6.3	Many plants, no nodules	2, 2, 3, 4, 1	0.00	2.40
7532	5,500	—[d]	6.4	3, 1, 1, 1, 1, 2, 1, 1, 1, 1, 1, 2, 2, 1, 1	1, 1, 1, 2, 1, 1, 1, 2, 2, 3, 1, 1, 1, 1, 1	1.33	1.33

[a] History of plat before 1910 unknown.

[b] Also 12 tons manure in 1920.

[c] Also 12 tons of manure in 1922.

[d] Probably never.

In such an arrangement soil from Plat 7011 gave the least color and is in third place as regards least need for bacteria, while that from 7006 gave the greatest color and is in greatest need of legume bacteria. While such a comparison may not be all that may be desired, it indicates that, in general, the greater the acidity of the soil the fewer legume bacteria it supports and that the greater will be the response, as measured by nodule production on plant roots, to supplementing the legume bacteria therein.

EXPERIMENTS WITH MEDICAGO

In this test soil was collected from plats in a manner similar to that previously outlined. On November 30, alfalfa seed (*Medicago sative*) were planted. On January 6 the nodules on the roots of the plants were counted. The counts, with other data, are presented in Table 3.

The data presented in Table 3 were obtained from plants grown at a time of year when the days are shortest. In addition nearly every day was cloudy. As a result the plants grew very slowly. Preliminary tests with several of these soils that were made in September showed more difference between the inoculated and uninoculated averages. The data reported, however, point to the same conclusions as were obtained in similar tests with *Pisum* and *Trifolium* which are given in previous tables. It may be pointed out, though, that the reaction of the soil at which supplementary bacteria may be expected to result in greater nodulation is nearer neutral for *Medicago* than for either *Vicia* or *Trifolium*.

EXPERIMENTS WITH SOYBEAN

On July 15, samples of soil from various plats were planted to soybeans and on August 1 the nodules were counted. The data are given in Table 4.

TABLE 4.—*Effect on nodulation of supplementing the legume bacteria content with an artificial culture for soybean (Sojas max, Piper).*

Plat No.	Years in soybeans	pH	Average number of nodules per plant	
			Uninoculated	Inoculated
7005	1915	5.8	9.30	9.71
7011	1915	6.8	13.00	9.00
7532	1923	6.3	0.16	7.50
R 6	1924	5.8	4.00	4.00
R 7	1922	5.6	0.50	4.40

Data from only five plats are presented in Table 4. They are somewhat similar to those presented in previous tables and point in a general way to the same conclusions.

DISCUSSION

The results secured in this study lead to the conclusion that the legume bacteria may entirely or largely disappear from soil. This disappearance seems to run parallel with increasing acidity of the soil and shows no consistent relation to the frequency of the host plant in the rotation. Soils which had not grown the host plant for 15 years or longer but which had been limed from time to time contained enough legume bacteria to supply the greatest needs of the seedlings. Other plats which probably have never grown the host plant (*Medicago sativa*), but which also have been limed from time to time, contain an abundance of legume bacteria. Still other plats of the same soil which had not been limed within 15 years but which had grown the host plant (*Vicia sativa*) within one year of making the test seem to be deficient in legume bacteria.

Augmenting the proper flora in such a soil has resulted in a larger number of nodules on the seedlings. Whether this increase in nodulation would follow in field tests or not has not been determined. It also has not been established that a larger number of nodules per plant is necessary for maximum crop yield, but plants that have nodules on their roots grow better than those which do not. It is assumed, therefore, that greater nodulation means a better stand and greater yields.

An application of calcium carbonate at seeding time to a soil that had proved to be deficient in the proper legume bacteria and that had grown clover (*T. pratense*) did not result in materially increasing the visible nodules on the seedlings. Different results might have been secured had the carbonate been applied several weeks before seeding.

Not more than 3 pounds of soil was collected for making these tests. This size of sample may have had some influence on the data which were obtained. In all probability some place or places in the plats may have contained the sought-for legume bacteria, but in sampling these places may not have been touched.

The fact that bacteria which produce nodules on alfalfa were found abundantly in a soil that had never grown alfalfa suggests that the ordinary farming operations, together with wind and probably other agencies, distribute the bacteria quite generally.

A consideration of the data in relation to the reaction of the soil leads to the conclusion that there is a rather definite pH of the soil at which each group of the legume bacteria will fail to produce nodules on plants or will altogether disappear.

SUMMARY

Soil samples were collected from plats whose crop and fertilizer treatment for about 15 years were known. They were used as a medium in which nodule production could be determined. Each sample was divided usually into two parts. One was used as a check against the other which was inoculated with an artificial legume bacteria culture for the particular legume studied. Moisture was controlled so that each part had approximately the same amount throughout the experiment.

Host plants of four groups of legume bacteria were grown on these soil samples. These four groups were of crops commonly grown in New York. They were *Vicia* and *Pisum*, *Trifolium Medicago* and *Melilotus*, and *Sojas*. When plants of these four groups had grown sufficiently so that nodulation had occurred they were washed free from soil and the nodules counted. The increase in numbers of nodules in the inoculated over the uninoculated was used as a measure of the benefit to the plant of the supplementary legume bacteria. This increase also indicated whether or not the soil maintained the bacteria in sufficient numbers to produce maximum nodulation or to meet the requirements of the plantlets.

It is concluded from experiments conducted in this manner that soils may be or may become an unfavorable habitat for the various groups of legume bacteria, that the bacteria may largely or entirely disappear from soil, that this disappearance goes hand in hand with increasing acidity of the soil, that the bacteria do not seem to be greatly influenced by the frequency of the host plant in the rotation, and that in acid soils the addition of more bacteria has resulted in the formation of a larger number of nodules per plant.

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CHARLES VANCOUVER PIPER

Charles V. Piper, ex-president and recently elected Fellow of the American Society of Agronomy, died at Washington, D. C., February 11, 1926. He was 58 years old and leaves a wife, mother, three brothers, and three sisters. The immediate cause of his death was uremic poisoning due to Bright's disease. Because of high blood pressure he had been forced to be careful in his work for several years, but was actively discharging his official duties up to four days before his death.

Mr. Piper was born at Victoria, B. C., June 16, 1867, one of the nine children of Andrew William and Minna (Hausman) Piper. After completing his common school work he entered the University of Washington and received the degrees of Bachelor of Science in 1885 and Master of Science in the same institution in 1892. In 1893 he went to Pullman, Wash., as Professor of Botany and Zoology in the Washington Agricultural College (now State College, of Washington) and remained as head of that department until 1903. He was married to Laura Maude Hungate on September 15, 1897. While connected with the State College at Pullman, Wash., he attended summer school at Harvard University and obtained an M. S. degree there in 1900. Since 1903, he has been continuously associated with the U. S. Department of Agriculture at Washington, D. C. He was in charge of the office of Forage Crop Investigations from its organization as a separate unit in 1905 until his death.

Mr. Piper was elected to two honor fraternities, Phi Beta Kappa and Sigma Xi, and was granted the D. Sc. degree by the Kansas Agricultural College in 1921. Besides the American Society of Agronomy, he was a member of the American Association for Advancement of Science, the Washington Academy of Science, the Biological Society of Washington, and the Botanical Society of Washington (President 1908-09). He was a member of the Division of Biology and Agriculture in the National Research Council, and chairman of the Subcommittee on Crops in the Advisory Board from the American Society of Agronomy.

In the death of Dr. Piper, agriculture and the biological sciences in general lost a most efficient worker. A survey of his life work indicates that he had an astonishing capacity for productive effort. In the last ten years of his life he was successfully discharging tasks that would ordinarily demand the time and energies of at least three men. He was administrative officer in charge of the Office of Forage-Crop Investigations, U. S. Department of Agriculture, and personally directed and carried on the experimental work with grasses and miscellaneous forage plants; chairman of the Green Committee of the U. S. Golf Association, and Editor of the Green Section Bulletin; Editor of the Agricultural Series of McGraw Hill books and of the agronomy division of Botanical Abstracts; and Associate Editor (Crops) for the Journal of the American Society of Agronomy. With all these duties demanding his attention, he found time to write an authoritative text book on forage crops and numerous scientific articles and papers relating to botany and agronomy.

He was first and foremost a botanist, recognized all over the world for his broad knowledge of plants and their taxonomic relationships. His interest in biology in general was such, however, that his activities were not confined to systematic botany. He knew insects almost as well as he knew plants, and in his later years contributed effectively to advances in agronomy.

His botanical training no doubt made him sensitive concerning nomenclature, for he carried into his agronomic activities a lasting interest in the proper evaluation of words. He became the proponent of many new agronomic terms and served as chairman of the standing committee on Agronomic Terminology in the American Society of Agronomy.

In 1911, Dr. Piper was requested by the War Department to make a survey of forage possibilities in the Philippine Islands to determine what might be done in the way of growing hay there for army purposes He spent four and one-half months on this task and returned by way of Java, India, Egypt, and Europe, collecting plants and seeds for the Department of Agriculture, and visiting botanic gardens and museums en route. Pleased with his suggestions as to forage in the Philippines, the War Department asked him to visit the Panama Canal Zone on a similar mission. He made this trip in February of 1923, familiarizing himself with the botanical characteristics of the flora and recommending methods for the production of forage for army horses and mules. Another foreign trip was made in 1924, under the auspices of the U. S. Golf Association, for the purpose of studying turf and turf grasses on European golf courses. As a result of these studies and his broad knowledge of methods of propagation and care of the turf grasses used on American golf courses, he became a recognized authority on golf-turf problems. More than any other he is responsible for devising the method of vegetative propagation of bent grasses in the establishment of greens on golf courses.

In Dr. Piper's conduct of forage investigations his most spectacular achievement was his introduction of Sudan grass into the United States. The finding of this valuable annual hay-grass in Egypt was the result of a conception in his own mind that there probably existed somewhere a grass similar to Johnson grass, but without tbe underground stems or rhizomes; an intermediate in the evolutionary series from Johnson grass to the cultivated sorghums. Search for this rhizomeless form of Johnson grass was inaugurated by sending requests to numerous botanists and agricultural workers in the Old World asking for seed of *Sorghum Halepense*. Among the many small lots of seed obtained was one from the Director of Agriculture of the Sudan Government, Khartum, Sudan. Although labeled *Sorghum Halpense*, this seed proved to be that of an annual grass entirely devoid of undergound stems. This grass, Piper named Sudan grass. Since 1918, the crop has been estimated to be worth over $10,000,000 annually to the United States.

His intimate acquaintance with the vegetation in all parts of the United States, especially those plants which are of most agricultural importance, convinced Dr. Piper of the great value of plant introductions. He was inclined to wax enthusiastic in his discussions of the increased aggressiveness exhibited by many foreign plants when they were brought into the United States, and became a confirmed searcher for new grasses and legumes. His wide acquaintance with foreign botanists and his botanical training enabled him to prosecute this quest for new and valuable plants more effectively than most men. The southeastern states have benefited most largely from this hobby of his. Proper appreciation of the value of Natal, Rhodes, Napier, Carpet, Kikuyu, Angleton, Bahia, and Centipede grasses; Brazilian joint-pod, a promising new legume; and many new varieties of velvet beans and soybeans; is largely due to his personal advocacy of their usefulness in that section. Hundreds of new grasses and legumes have been tested under his direction at experiment stations in the cotton belt.

Dr. Piper was a prolific writer, the number of publications which bear his name comprise in themselves an enviable life work. His seven books included three, The Flora of the Palouse Region (1901), Flora of Southeastern Washington and Adjacent Idaho (1914), and Flora of the Northwest Coast (1915) in collaboration with R. Kent Beattie; Turf for Golf Courses (1917) in collaboration with R. A. Oakley; The Soybean (1923) in collaboration with W. J. Morse; and two of which he was sole author, Flora of the State of Washington (1906), and Forage Plants and Their Culture (1914). A second and enlarged edition of the last-named book came from the press in 1924. In addition to these books he issued between 1893 and 1926 fifty-one botanical papers all but one of which he was sole author, and fifty-five agricultural papers and bulletins (see attached list) of which he was sole author but many of which he published as senoir author in collaboration with his associates. No mention has been made in this list of over one hundred articles written for the Green Section Bulletin.

Some men who did not know Dr. Piper intimately regarded him as a "knocker" because of his tendency to question and criticize freely. His criticisms, however, were almost invariably constructive. When pointing out a weakness he usually suggested a remedy. His vision and originality of thought attracted many workers to his. office for assistance with their problems. To his associates in the Office of Forage-Crop Investigations Dr. Piper was always an inspiring leader and an invaluable counselor, never too busy to identify a plant or discuss a problem—to them his untimely death was a tragedy.

H. N. VINALL.

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BOOK REVIEWS

OATS; THEIR VARIETIES AND CHARACTERISTICS

A Practical Handbook for Farmers, Seedsmen, and Students

By H. Hunter. Pub. by Ernest Benn, London, Eng. 127 pp. 18 figs. 1924.

This little volume contains much that will interest American agronomists and farm crops students, though most of the varieties described are suitable for culture in the British Isles rather than in the United States. Professor R. H. Biffen of Cambridge University has contributed a brief introductory chapter in which he calls attention to the fact that farmers, seedsmen and students are often in need of information on varieties of oats, which is not generally available in a form of direct use to the practical man.

Chapter headings are as follows: Introduction, The Origin of Cultivated Oats, Botanical Characters of the Oat Plant, Species of Oats, Classification and Description of Varieties of *Avena sativa*, The Chemical Composition of Oat Grain, Seed Selection, The Production of Pure Seed.

The following species of *Avena* are described, *A. nuda*, *A. sterilis*, *A. fatua*, *A. abyssinia*, *A. strigosa*, *A. brevis*, *A. sativa*, and *A. sativa orientalis*

The varieties of *A. sativa* are placed in five sub-groups, as follows: (1) winter-hardy, (2) semi winter-hardy, (3) potato, (4) abundance, and (5) early ripening; while sub-groups (6) and (7) include forms of *A. sativa orientalis*. This scheme of classification seems a convenient one for the use of the English farmer, seedsman and student, but is hardly logical from the taxonomic viewpoint, and might be confusing if it had to be used with a larger number of varieties. American students, many of whom have been taught that all cultivated oats belong to the two species *A. sativa* and *A. sterilis*, will find it interesting to note that forms of *A. strigosa* are grown on farms in the Shetland Islands and at high altitude in Wales.

The student of crop improvement will note that of the list of about forty cultivated varieties which are described by the author, thirteen have resulted from the plant breeding efforts of English seedsmen (eleven from Gartons, two from Webbs), nine are the result of plant breeding research at Svalof, seven are known introductions from the European continent, or from Canada, four may be described as "old land sorts" grown in the British Isles for so long a time that their exact origin is unknown, two, Potato, 1788, and Sandy, 1824, are fortunate selections made by farmers, three are hybrids of known parentage made by the author. Many of the Garton productions are selections from composite crosses. Whatever may be said in criticism of the plant breeding efforts of seedsmen, it is interesting to find that one firm is responsible for more varieties of oats grown in England than any other agency. The debt owed to the Swedish Seed Association by English farmers is shown by the number of varieties originated at Svalof.

Those engaged in experimental work with cereals will find several questions raised in this book on which further research is greatly needed. Thus with respect to winter hardiness in relation to other characters, the author says (page 43), "the winter sown varieties are distinguished by longer, finer straw and abundant tillering, whilst the spring sown forms possess shorter straw and a considerably poorer tillering capacity." Also, "the late ripening sorts are generally those exhibiting greatest relative winter hardiness." One would like to know more of the physiologic or genetic basis of these observed correlations. On page 92, the author presents certain data bearing on the moot question of size of seed as related to yield of grain which indicate that for the material used high values for air dry weight of 1000 kernels are correlated with yield of grain. Further critical studies of this and other factors affecting yield in the cereals are needed.

The book contains a very few statements which seem incomplete, incorrect or possibly misleading. For instance on page 22 in describing juvenile plant characters the author states that wheat usually has a prostrate habit of growth, and barley generally an erect habit. The student should recognize that there are numerous varieties of spring wheat which are erect in early growth, and that a fair though relatively small number of winter barleys have a spreading habit of early growth. For the English student who may later find himself dealing with oats as a farm crop in the southern United States, it might be well to complete the statement with reference to varieties of *S. sterilis* (page 35) as follows: "The cultivated forms of this species are widely distributed and extensively cultivated in the countries bordering the Mediterranean," and in the *southern United States*.

The author has followed the classification of Etheridge (page 49) in describing Kherson as a yellow oat and Sixty Day as white. As Warburton and Stanton have shown these two names refer to what appear to be almost identical lots of seed imported from Russia, both kernel colors are to be found under each name.

The American student of oat varieties and their adaptation will probably critically examine the statement (page 104) that "other conditions being equal, considerable advantage is sometimes obtained by cultivating early ripening varieties in northern districts." Perhaps "other conditions are not equal," at any rate the early varieties do not find their greatest usefulness in the northern United States, but rather in the middle states. Thus the early varieties Kherson or Sixty Day and Burt are much better adapted in Iowa, Nebraska and Kansas than are such later varieties as Silvermine, Swedish Select and White Tartarian, which produce better yields in some of the northern states.

The printer and proofreader have allowed a few typographical errors to creep in, as on pages 10, 14, 51 and 98. The word *between* is used on page 22 where the word *among* would be preferable. JOHN H. PARKER.

AN AGRICULTURAL ATLAS OF ENGLAND AND WALES

Published by Direction of the Ministry of Agriculture and Fisheries (London) by the Ordinance Survey. (Southampton) England.

Mr. J. Pryse Howell, on behalf of the Agricultural Economics Research Institute, University of Oxford, has prepared a most useful atlas, which will be of interest not only to those directly concerned with English agriculture, but to American agronomists as well. There are 22 maps showing the areas and distribution of permanent grass; arable land; wheat; barley; oats; beans; peas; potatoes; turnips and swedes; mangolds; vetches or tares; hops; lucerne, clover, sainfoin and grasses under rotation; bare fallow; also certain classes of livestock. These maps are Heliozineographed on transparent paper. The volume also contains excellent geological, rainfall, relief and town maps. These are loose and any desired one can be placed under the distribution map for any particular subject or crop, thus giving an immediate and clear visualization of the relation, say, between the distribution of wheat and rainfall, or of a crop industry in any particular region or market center.

One is reminded, in using this atlas, of the very similar and equally useful work on the graphics of American and world agriculture by Mr. O. E. Baker and his associates in the U. S. Department of Agriculture at Washington.

Brief textual references and statistical summaries (by counties) accompany each map. In this review it is not possible to quote from more than three of these paragraphs; those dealing with wheat, oats and barley. In 1918, when the data for these maps were collected, wheat occupied about two and one-half million acres in England and Wales, or 21 per cent of the arable land. The wheat crop is pretty regularly distributed with the arable land, though the most favored areas are the eastern and midland counties. The relationship between the rainfall and wheat is very clearly marked, most of the crop being grown in those areas having less than 40 inches average annual precipitation and practically none in areas having over 60 inches. Wheat has a wide range of soils and is grown on well nigh every variety from the light silicious soils of the eastern counties to the difficult clays. Wheat does best on heavy loams and clays.

Oats is the chief cereal crop of England and Wales, and occupied just over two and a half million acres, or 22 per cent of the arable land, in 1918. It is grown in every district and under widely different conditions of soil and climate; in some parts where other cereals do not flourish. Oats are especially adapted to those districts having a moist atmosphere and a low and equal range of summer temperature, and are chiefly grown in the western and northern countries. Their cultivation in the east and southeast is subordinated to that of wheat and barley, owing to the dryness of the climate and a high summer range of temperature. A considerable acreage of oats is indicated for areas having 80 inches of rainfall, but most of the oat area is under the 60-inch zone and the 600-foot level.

Barley occupied about one and a half million acres, or 12 per cent of the arable land The barley crop has a fairly wide distribution and can be grown under almost any conditions of soil and climate, though it is only in certain districts that a sample of malting quality can be produced The chief barley belts occur in those counties with an annual rainfall of under 30 inches and an altitude not exceeding 200 feet, though in Wales barley is grown in regions with a rainfall up to 60 inches and an altitude of from 400-600 feet The barley districts follow the chalk formation and the Tertiary Deposits, the light sands of Norfolk and Suffolk, the Limestone soils of the Lower Oolites, the soils of the Upper Greensand, and the lighter descriptions of drift soils. The best barley is grown in Cambridge, Norfolk and Suffolk, Lincoln, Essex and Kent, and some parts of Devon, Cornwall and Somerset.—JOHN H. PARKER.

REPORT OF PROCEEDINGS, IMPERIAL BOTANICAL CONFERENCE, LONDON, 1924

Edited by F. T. Brooks, published by Cambridge University Press, 1925.

This volume contains reports and papers of interest to every American botanist (physiologist, geneticist, plant pathologist, and taxonomist) and agronomist. It is significant that this representative group of English botanists should devote much of their time, as reflected in the pages of this report, to a discussion of economic problems in the fields of plant physiology, plant pathology, genetics, taxonomy and ecology. Sir David Prain served as President of the conference.

The following papers forming a symposium on "The Physiology of Crop Yield" will be of special interest to agronomists: General Introduction, by F. F. Blackman of Cambridge; Experiments on Plant Growth with controlled Light and Temperature, by F. G. Gregory; The Electrical Conditions of Plant Growth, by V. H. Blackman; Developmental Analysis of Crop Yield, by W. L. Balls; Plant Yield and Intensity of External Factors, by G. E. Briggs; The Technique of Plot Experiments, by E. J. Maskell; The Analysis of Weather Crop Data, by R. A Fisher; Analysis of Cereal Yield, by F. L. Engledow; Rainfall and Crop Yield in the Tropics, by H. M. Leake.

One session of the conference at which Mr. W. Bateson presided was devoted to genetics The following papers were read: The Economic Possibilities of Plant Breeding, by F. L. Engledow; The Inheritance of Cropping in the Potato, by R. N. Salaman; Sugar Cane Breeding in India, by T. S. Veukatraman; The Value of Selection Work in the Improvement of Crop Plants, by John Percival; Selection work on Herbage Plants, by R. G. Stapledon; Defects in the Theory and Practice of Selection, by W. L. Balls; The Value of Selection Work in the Improvement of the Flax Crop, by G. O. Searle; Selection of High Yielding Varieties of Rice in Malaya, by W. N. Sands.

Another section of the conference program dealt with plant Pathology and mycology under the chairmanship of Prof. John Percival. Mr. F. T. Brooks read the first paper, "The Relation of Plant Pathology to Genetics." Mosaic diseases of sugar cane and other crops were discussed under the leadership of Dr. E. J. Butler.

Rules of Plant Nomenclature were considered by the conference, as were the general subjects of botanical education and research.

Mr. J. M. F. Drummond read an interesting paper on "The Formation of Herbaria of Crop Plants."

Among the American botanists who attended the conference were Dr. E. M. East of Harvard, Dr. C. V. Piper of the U. S. Department of Agriculture, and Professor J. A. Schramm of Cornell.

JOHN H. PARKER.

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SYMPOSIUM ON "THE PRESENT STATUS OF CORN IMPROVEMENT"

Leader: Frederick D. Richey, Agronomist in Charge of Corn Investigations, Office of Cereal Investigatons, U. S. Department of Agriculture.

1. "Introductory Remarks." Frederick D. Richey.

2. "The Relation of Inheritance Studies to Corn Improvement." A. M. Brunson, Bureau of Plant Industry, United States Dept. of Agriculture, Kansas Agricultural Experiment Station.

3. "The Influence of Temperature upon the Metabolism and Expression of Disease Resistance in Selfed Lines of Corn." James G. Dickson Wisconsin Agricultural Experiment Station, and James R. Holbert, Bureau of Plant Industry, United States Dept. of Agriculture, Bloomington, Illinois.

4. "Some Differences in the Functioning of Selfed Lines of Corn under Varying Nutritional Conditions." G. N. Hoffer, Indiana Agricultural Experiment Station.

5. "The Comparative Water Economy of Selfed Lines of Corn and their Hybrids." T. A. Kiesselbach, Nebraska Agricultural Experiment Station.

6. "Present Day Problems of Corn Breeding." H. K. Hayes, Minnesota Agricultural Experiment Station.

1. INTRODUCTORY REMARKS[1]

FREDERICK D. RICHEY[2]

It would be pleasant to open this symposium by pointing with pride to the steady increase in the acre yield of corn in the United States that had resulted from the successful efforts of the corn breeders of the country. In the absence of the basic data necessary to such an opening, it would be equally pleasant to introduce a series of speakers who could present conclusive evidence of significantly increased yields which were due to breeding, obtained over relatively large areas for reasonably long periods of time. Unfortunately, there also is a lack of the material necessary to such a proceeding.

This is not intended to imply that breeding has accomplished nothing in the way of corn improvement. It seems incontrovertible that much if not all of the adaptation of corn to the many conditions under which it now is grown was accomplished by conscious selection. Indeed, corn is so poorly adapted to survive under natural conditions as to make it not impossible that *Zea mays* itself is the product of some prehistoric plant breeder. What methods were followed prior to the discovery of America is unknown. Most of the progress since then, however, has been the result of careful mass selection, either alone or following hybridization.

Some of the higher-yielding varieties of more recent origin were developed by ear-to-row selection, though whether better results were obtained by this method than could have been achieved through careful mass selection is problematic. Certainly, the evidence from varietal trials shows few if any varieties or strains developed by ear-to-row breeding which are on a materially higher plane of productiveness than the best of the mass-selected varieties in the locality.

Considerable increases in yield have been obtained experimentally from F_1 crosses between varieties of corn. For some reason, however, the use of such crosses has never become popular with the farmer and the interest which experimenters were taking in this method of improvement a few years ago has been transferred largely to methods involving selection within self-fertilized lines.

A consideration of mass selection, ear-to-row breeding, and the possibilities in F_1 varietal hybrids, however, was more appropriate to the symposium on corn breeding held at the winter meeting of this Society five years ago than it is here. The subject today is, "The *Present* Status of Corn Improvement," and this must needs exclude from consideration any method not involving some degree of selection within self-fertilized lines. True, mass selection—or ear-to-row breeding—still may be utilized to raise the productiveness of inferior or unadapted sorts to a level approximating that of the better varieties. Mass selection also is an important means of maintaining productiveness in adapted strains. Improvement, however, implies more than this, and it is by methods involving selection within self-fertilized lines that the corn breeder of today is attempting to obtain yields significantly larger than those which now are produced by our best varieties.

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[1] Paper read as a part of the symposium on "The Present Status of Corn Improvement" at the meeting of the Society held in Chicago, Ill., November 17, 1925.

[2] Agronomist in Charge of Corn Investigations, Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C.

At first sight this may seem a rather restricted program. It should be noted, however, that nothing is said as to the number of generations during which self-fertilization must be continued, or whether the seed finally planted on the farm shall be an F_1 cross, a double cross, a resynthesized variety, or what not. The only restriction is that selection within self-fertilized lines shall be one phase of the operation. Eventually the proof of the soundness of this program will be the yields of corn obtained from strains developed by methods included within it. As yet, however, the methods have not been in use long enough to provide empirical evidence of their value in increasing acre yields on the farm. In fact, the present status of corn improvement may be said to be one of transition. For the present, therefore, reliance must be placed, first upon the soundness of the underlying theory on which the methods are based, and second upon such direct evidence of improvement as has been accumulated. Accordingly, this morning's program was planned to present evidence from both of these points of view.

This evidence is to be presented in five parts. Inasmuch as selection within self-fertilized lines as a basis for corn improvement was conceived as a result of advances in fundamental genetic knowledge, it is fitting that the first paper on the program should deal with inheritance in corn. Following this are three papers which consider differences in the functioning of self-fertilized lines with relation to temperature, nutrition, and water requirement. The final paper presents a summary of some of the increased yields that have been obtained by methods involving selection within self-fertilized lines and discusses problems that must be solved before the better methods of utilizing this principle can be determined.

2. THE RELATION OF INHERITANCE STUDIES TO CORN IMPROVEMENT[1]

ARTHUR M. BRUNSON[2]

Many of us still hold, at least in our subconscious minds, a subtle distinction between research in "pure" and "applied" science, although the opposite view has frequently been championed by men of note. A distinction may be made, to be sure, between investigations which are pursued with no objective other than to understand the workings of natural phenomena or to systematize knowledge in some chosen field, and those which are instigated to solve some urgent practical problem. It is a curious commentary of science that knowledge gained for the fun of untangling one of Nature's puzzles frequently has made possible applications of the greatest economic importance many years later. Conversely, truths of profound scientific importance have been uncovered in the pursuit of the most utilitarian objectives when scientific methods have been employed. The history of most branches of science shows that they progress from the stage of empiricism to that of inductive reasoning as more and more facts are accumulated and classified.

Corn improvement in the past has been carried on largely by empirical methods but during recent years has made notable advancement in method with much promise for the future. At the same time a considerable fund of knowledge concerning the inheritance of certain qualitative characters has been accumulated and generalizations have been made so that the hereditary behavior of these characters under any given conditions can be predicted with assurance. It would seem that the time is at hand when advantage should be taken of these generalizations, and the genetic method be applied to the solution of the complex problems of inheritance of function, to the end that corn improvement be placed on a more scientific basis.

The maize plant affords unusually favorable material for breeding investigations and the opportunities it offers have been exploited by many workers It can be grown under a wide range of conditions including the climatic range of practically all of this country. The technic of controlled pollination is very simple and results in a large number of seeds from a single operation, thus making back crosses feasible and enabling the investigator to deal in large numbers of progeny with comparatively small effort. A wealth of material in the way of heritable variations, including many endosperm and seedling characters, is at hand to offer unexcelled opportunities for genetic studies. The plant is an annual but where greenhouse facilities are available two (and in rare instances more) generations may be grown in a year. In addition to these advantages corn ranks economically as a premier crop plant of the country.

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[1] Paper read as a part of the symposium on "The Present Status of Corn Improvement" at the meeting of the Society held in Chicago, Ill., November 17, 1925. Joint contribution from the Department of Agronomy, Kansas Agricultural Experiment Station, and the Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture. Department of Agronomy Contribution No. 160.

[2] Associate Agronomist, Bureau of Plant Industry, United States Dept. of Agriculture, Agricultural Experiment Station, Manhattan, Kan.

The genetics of corn has been developed by an illustrious list of workers both in this country and in Europe. Probably more is known concerning inheritance in *Zea mays* than in any other species in the plant kingdom. Ever since Correns used it as one of the plants with which to verify Mendel's great discovery it has been in the forefront in assisting to explain the mysteries of inheritance. Contributions to our knowledge of xenia, non-disjunction, mutations, linkage, and more recently cytology, have all been made through the medium of this species. At present the breeding behavior of approximately 100 factors has been worked out, including complicated characters illustrating complementary action, inhibitory factors, multiple effects of a single factor, and duplicate genes. Thus far the evidence accumulated in corn has served to confirm and amplify our concept of Mendelian inheritance. There is every reason to believe that we have in this species another example of strictly factorial inheritance in which workers may predict with assurance definite results from a given mating every time it is made, once the factors involved and their methods of inheritance are known. This may be pointed out as the first contribution of inheritance studies to corn improvement. Although at first thought it may be supposed that this assurance may be taken for granted, the accumulated evidence nevertheless provides a solid groundwork based on scientific fact upon which to build with confidence.

In the advancement of linkage studies corn stands out pre-eminently in the plant kingdom. It is the closest competitor of *Drosophila*, with which such epoch-making discoveries have been made. Eight linkage groups are known at present, as shown in Fig. 1. We have reasonably good evidence that they are independent and distinct. Cytological studies show that there normally are ten pairs of chromosomes in maize. It is with considerable interest that we await the filling of the remaining gaps to see whether or not genetic evidence will confirm the chromosomal theory of inheritance in this species.

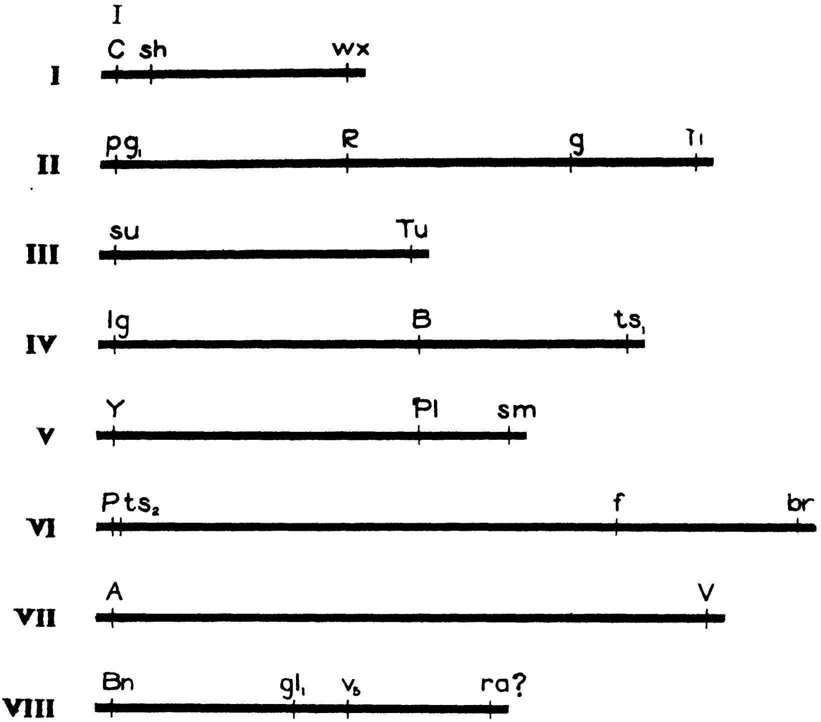

FIG. 1.- The eight established linkage groups in corn.

Corn contains ten pairs of chromosomes of which eight have so far been assigned to independent linkage groups. The loci of genetic factors on these eight chromosomes, are shown by the symbols which refer to the following characters:

I	dominant inhibitor of aleurone color	sm	salmon colored silks
C	necessary for aleurone color	Pl	involved in plant color
sh	shrunken endosperm	Y	yellow endosperm
wx	waxy endosperm	f	fine-striped leaves
pg_1	pale green seedlings	P	pericarp and cob color
R	necessary for aleurone color	ts_2	tassel seed
g	golden plants	br	brachytic culms
li	lineate leaves	A	anthocyanin pigment
su	sugary endosperm	v	virescent seedlings
Tu	tunicate condition	Bn	brown aleurone
lg	liguleless leaves	gl_1	glossy seedlings
B	involved in plant color	v_5	virescent seedlings
ts_1	tassel seed	ra	ramose inflorescence

It would seem that the rapidly increasing knowledge we have concerning linkage offers the most promising avenue of assistance to corn improvement from corn genetics. The chromosomal theory of inheritance and the phenomenon of linkage are the foundation upon which East and Jones have already postulated their hypothesis to explain heterosis on the basis of linked dominant favorable growth factors. This explanation seems to fit the known facts of the case and offers the best working hypothesis that we have at the present time. An experimental proof of the proposition would encounter many difficulties, but it appears now that the most promising attack lies in the use of our detailed knowledge concerning the linkage groups in corn.

This bring us to the possibility of locating those intangible and hitherto elusive factors which in their aggregate make for a desirable individual under a given set of conditions. We have every reason to believe that the complex of characters which go together to make a desirable strain of corn are inherited just as definitely, and are represented by individual factors in the germ cell just as surely, as are the characters of aleurone color or endosperm texture, for example. In making linkage studies it is natural that the characters used thus far have been the obvious, easily distinguished morphological ones which lend themselves to easy separations and exact counts. With an outline representing the chromosomes, however, and marked at various points by factors representing easily distinguishable characters, it should be possible to learn much concerning the inheritance of the more intangible characters of so much economic importance in corn improvement. With this information at hand the production of superior strains would be transferred from an empirical to an exact basis.

At present we have no idea of the number or relative importance of the factors which may be involved. It may be inferred, however, from the great diversity of inbred lines, that the number is not small. It also seems probable that there may be a few whose importance far outweighs the others. Lindstrom[3] has recently given a good example in the tomato of the linkage between the factor for skin color and a factor or linked group of factors which largely determine the size of fruit. If we knew the mode of inheritance of a few important physiological factors in corn and could definitely assign them to linkage groups, it would greatly simplify our procedure and increase the probability of final achievement.

During the last few years the general adoption of controlled pollination has produced large numbers of inbred strains in various parts of the country. As a result, considerable attention has been directed toward that most interesting question of variations in the physiology of different inbred lines. Strains that differ in their ability to obtain the various inorganic plant food materials from the soil, strains that differ in their relative rates of growth under varying temperatures, and strains that differ in their relative water economy may be mentioned as examples of the various angles of the problems which are being studied. Equally important are the studies being conducted on variation in resistance to disease. In the case of corn smut, we not only have some strains completely susceptible and others very resistant, but we have strains which are susceptible in one organ or location only, while other strains seldom or never exhibit infection at that location but may be uniformly susceptible at other points. Conversely, in the case of the rot diseases, a single structure may be subject to attack by several organisms, but here again susceptibility is very specific and a strain resistant to one organism may or may not be resistant to another.

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[3] LINDSTROM, E. W. A genetic linkage between size and color factors in the tomato. *In* Science, 40:182–183. 1924.

The use of inbred strains and of controlled pollination have had no small part in the success of these researches. Uniformity within a given generation and the ability to duplicate and control hereditary elements as well as environmental conditions are essential and are possible only in selfed lines which have reached a reasonable degree of homozygosity and in F_1 crosses between such selfed lines.

After the isolation of selfed strains possessing desirable qualities of functioning the question arises as to their best utilization. Is it not here that genetics offers the most promise to corn improvement in the near future? In the first place we need to know the mode of inheritance of these characters to combine them intelligently into economically desirable hybrids. Do the characters behave as dominants or recessives? Do they depend on one factor or many and, if the latter is the case, may not one or two most important factors be singled out? Must the desirable factors be introduced from both parents, i. e., be homozygous in the hybrid, to give the best results? Answers to these and other questions are needed to permit the best utilization of the desirable selfed lines, through furnishing additional knowledge concerning the mechanism of reaction to a specific environment, and how this ability to react is transmitted from one generation to the next.

In the second place, genetic knowledge concerning the mode of inheritance of these evasive physiological characters may enable us to transfer them from one selfed line to another. It is common experience that one selfed line excels in a given quality but is weak in another, in contrast to other lines in which exactly the reverse is true. For instance, a certain line may be nearly immune from smut attack but may be undesirable because of a weak root system. If it were known, on the basis of inheritance studies, that not too many factors were involved for each character and that the principal factors for the two characters were not too closely linked, it should be possible to recombine the unusual smut immunity of the one line with the strong root system and erect habit of some other line more easily than to produce a large number of new lines in the search for a chance favorable combination.

A third possibility, which really is an elaboration of the second, is the synthesizing of true breeding "super-lines" which will incorporate the outstanding desirable qualities from several of the best foundation selfed lines. This may prove too complicated ever to be done, or probably will not be attempted until some years hence when more is known of the inheritance of the various factors involved. Harrington and Aamodt[4] have already suggested a similar procedure in the synthesis of a wheat which would be resistant to all the physiologic forms of stem rust.

In this connection it should be emphasized that in the multitude of selfed lines recently developed we have something entirely new in corn as far as breeding behavior is concerned. As each strain approaches homozygosity after a few years of inbreeding it becomes a uniform true-breeding entity which can be relied upon to give uniform progeny under given environment and to remain constant through succeeding inbred generations. Two lines of corn developed from a common origin may be as different as two distinct varieties of wheat and may give fully as much opportunity for making recombinations of desirable characters.

In corn, as in other crops, breeding for resistance offers one of the most feasible methods of controlling disease. A newer extension of this idea is shown in recent efforts to check or avoid the injury of certain crop insects by taking advantage of variation in some attribute of the host which enables it to resist or escape its enemy. In addition to general requirements there are many problems of a local nature. The Southwest needs a corn more resistant to hot winds, the dairy sections desire a corn better suited for ensilage, the North needs an early corn with ears higher from the ground, to mention but a few. The extreme diversity among inbred lines and the large numbers of such lines being grown gives us hope that

[4] HARRINGTON, J. B., and AAMODT, O. S. The mode of inheritance of resistance to *Puccinia graminis* with relation to seed color in crosses between varieties of durum wheat. *In* Jour. Agr. Res., 24:979-996. 1923.

many of the characters sought for will be found. After being fixed in the selfed lines they may be kept constant for study, or recombined to produce hybrid seed corn at will. If advantage is taken of the genetic method and the information we already have concerning inheritance in corn to work out the mode of inheritance of the desirable characters, the progress to the desired practical goal will surely be more certain, and it is possible will be faster than if purely empirical methods are followed. It presents an attractive and fertile field of research in which the contributions should be of great scientific and economic importance.

3. THE INFLUENCE OF TEMPERATURE UPON THE METABOLISM AND EXPRESSION OF DISEASE RESISTANCE IN SELFED LINES OF CORN[1]

James G. Dickson and James R. Holbert[2]

The future development of field crops is largely concerned with the study of genetic entities in response to their environment. The agronomist, the geneticist, the physiologist, and the plant pathologist, in other words, those most closely associated with the improvement of crop plants, must accept the fact that environment does influence plant development. Therefore, while each experimenter is approaching the problem from a slightly different angle, all are concerned with the expression of correlated genetic factors under a constantly varying environmental complex.

The pathologist of today, for example, whether studying a new disease, restudying a disease long known, developing control measures, or specifically selecting disease-resistant strains, must first chart the range over which environment influences disease development and, second, define the nature of this influence in terms of parasite, host plant, and disease. This problem varies with the different diseases. The simplest type, by far, is where the rather cosmopolitan parasite attacks the subterranean parts of many seedling plants, as for example in the common seedling blights of wheat and corn. The most complex type is where the specific, obligate parasite attacks the aerial parts of a limited number of varieties or strains within a species, as for example in the rusts of wheat and other grains.

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[1] Paper read as a part of the symposium on "The Present Status of Corn Improvement" at the meeting of the Society held in Chicago, Ill., November 16, 1925. The investigations upon which this paper is based were conducted cooperatively between the Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, the Wisconsin Agricutural Experiment Station, and Funk Brothers Seed Company.

[2] Associate Professor of Plant Pathology, University of Wisconsin, Madison, Wis., and Agent, Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agricuture; and Agronomist, Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, Bloomington, Illinois, respectively.

The studies reported herein deal specifically with one of these simpler types of diseases, the seedling blight of wheat and corn caused by *Gibberella saubinetii*. The regions of attack are primarily the protective sheath tissues, coleoptile and coleorhiza, and the cortex of the mesocotyl and primary roots. These are all tissues which mature very early in the development of the seedling and which, because the cortex of the coleorhiza is normally firmly joined to the pericarp at the juncture of cotyledon and endosperm, form a more or less continuous protective layer over the embryonic tissues, as well as the soluble foods within the cotyledon (scutellum) and the endosperm. The influence of temperature upon the development of seedling blight of wheat and corn and the correlation between disease development and seedling metabolism of the two hosts were reported in detail in a previous paper before this Society.[3]

For the purpose of clearness in presenting these later studies upon the development of seedling blight and its correlation with seedling metabolism in selfed lines of corn, the writers have taken the liberty of including these summary paragraphs of the previous work.

Wheat and corn seedlings blight at different temperatures. Wheat seedlings blight at high temperatures and remain healthy when grown below 10°C. Corn seedlings blight at low temperatures and remain healthy when grown above 24°C. A study of the development of the seedling blight indicates that the development of the disease is primarily concerned with (1) penetration of the fungus through the protective sheath tissues and (2) favorable substances for active growth when once within the tissues. In other words, the influence of temperature upon the development of seedling blight of wheat and corn is primarily a host response, and therefore, a study of the host plants should reveal something of the nature of these differences.

The metabolism of wheat and corn seedlings is influenced differently by temperature. Wheat seedlings grown at low temperatures (8°C.) are high in soluble, carbohydrate building-substances, principally dextrin, sucrose, and hexoses, and have cellulose cell walls

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[3] DICKSON, JAMES G. The relation of plant physiology and chemistry to the study of disease resistance in plants. *In* Jour. Amer. Soc. Agron., 17:676–695. 1925.

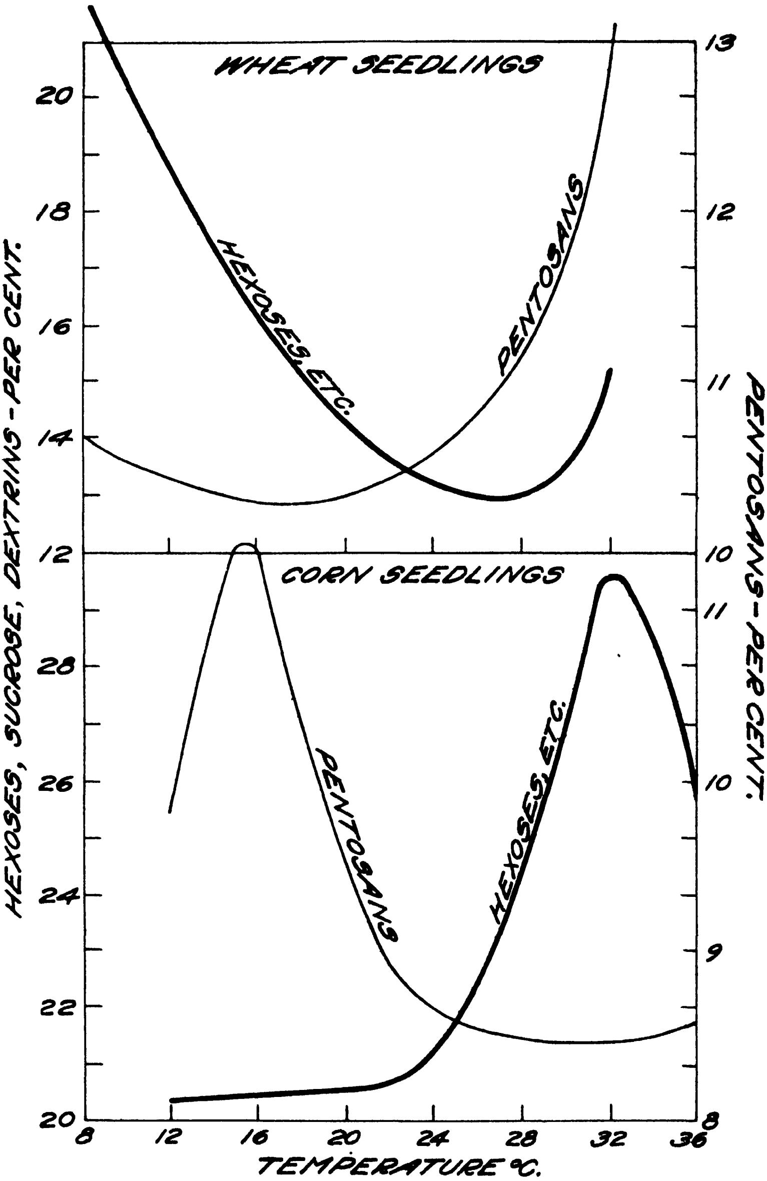

FIG. 1.—Curves showing the influence of temperature upon the composition of wheat and corn seedlings. The heavy lines represent such carbohydrate building-substances as hexoses, sucrose, and dextrins in the seedling with the endosperm removed. The light lines represent total pentosans, contained largely in the cell walls. Note the difference in the trend of these curves with the rise in temperature. Wheat blights badly at temperatures above 12°C., and corn at temperatures below 24°C.

with well-lignified walls in the cortical cells of the coleorhiza and coleoptile.[4] The wheat seedlings grown at high temperatures (16–24°C.) are relatively low in these building substances and have a high pentosan content. The cell walls of the protective sheath tissues in the high-temperature seedlings are largely intermediate pentosan-yielding substances. On the other hand, corn seedlings grown at low soil temperatures (8–20°C.) are relatively low in these soluble, carbohydrate building-substances and have cell walls, especially in the protective sheath tissues, composed largely of pentosan-yielding substances, giving the characteristic reactions of pectic materials. The corn seedlings grown at high temperatures (24°C. and above) have a large reserve of soluble, carbohydrate building-substances, principally sucrose, glucose, and fructose, and have cellulose walls, well impregnated with suberin, in the protective sheath tissues. (See Fig. 1.)

Fungus penetration is largely inhibited by cellulose cell walls reinforced with either lignin or suberin and the hexoses and other soluble polysaccharides found in either wheat or corn seedlings are relatively poor foods, whereas the pentosan-yielding substances, such as pectin and xylan, are excellent foods and produce five times more vegetative growth of the fungus than the simple sugars. Consequently, the conditions found in the seedlings at the different temperatures indicate a direct correlation between host metabolism and the development of seedling blight.

Disease-resistant and disease-susceptible strains of corn have been obtained during the progress of the work. The disease-resistant strains are capable of growing under unfavorable environmental conditions in heavily infested soils and still remaining healthy. For example, certain of the more resistant strains remain resistant to seedling blight until the temperature is lowered below 12°C., when they beome predisposed to seedling blight. These strains have given very satisfactory results under field conditions, as shown in Fig. 2.

Each self-pollinated line of corn studied has been found to have very definite temperature limits within which it is capable of resisting disease. Preliminary temperature studies have been conducted in the past two years on strains which have been self-pollinated and selected for seven and eight years and on hybrids between these strains. The results show that disease resistance is an inheritable characteristic the expression of which is constant over a given range

[4] The chemical analyses made in connection with these experiments were made by Karl P. Link and Allan Dickson and will be reported in detail in later papers.

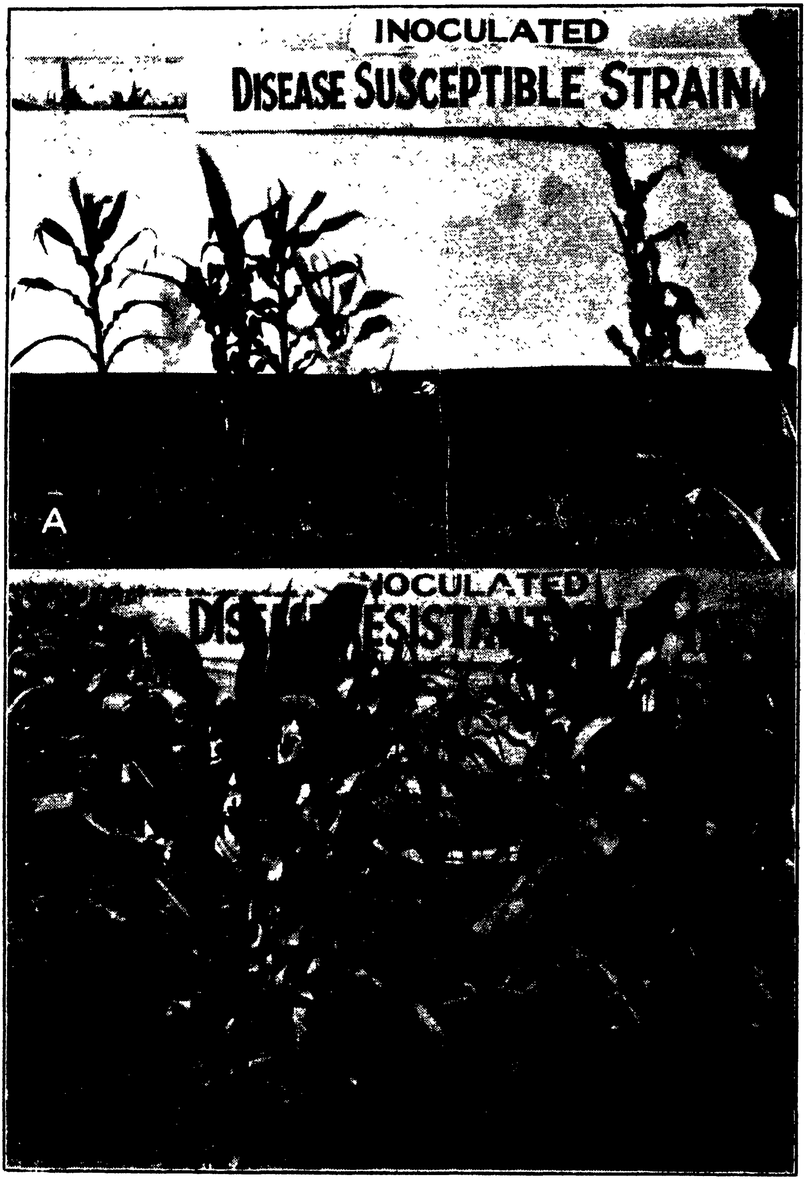

FIG. 2.—Susceptible (A) and resistant (B) selfed strains of yellow dent corn growing in soil heavily infested with the seedling-blight parasite. The two strains had been self pollinated eight years. Note the complete susceptibility in the one case (A) in contrast with a high degree of resistance in the other (B). These strains and others have been used in the studies reported in this paper.

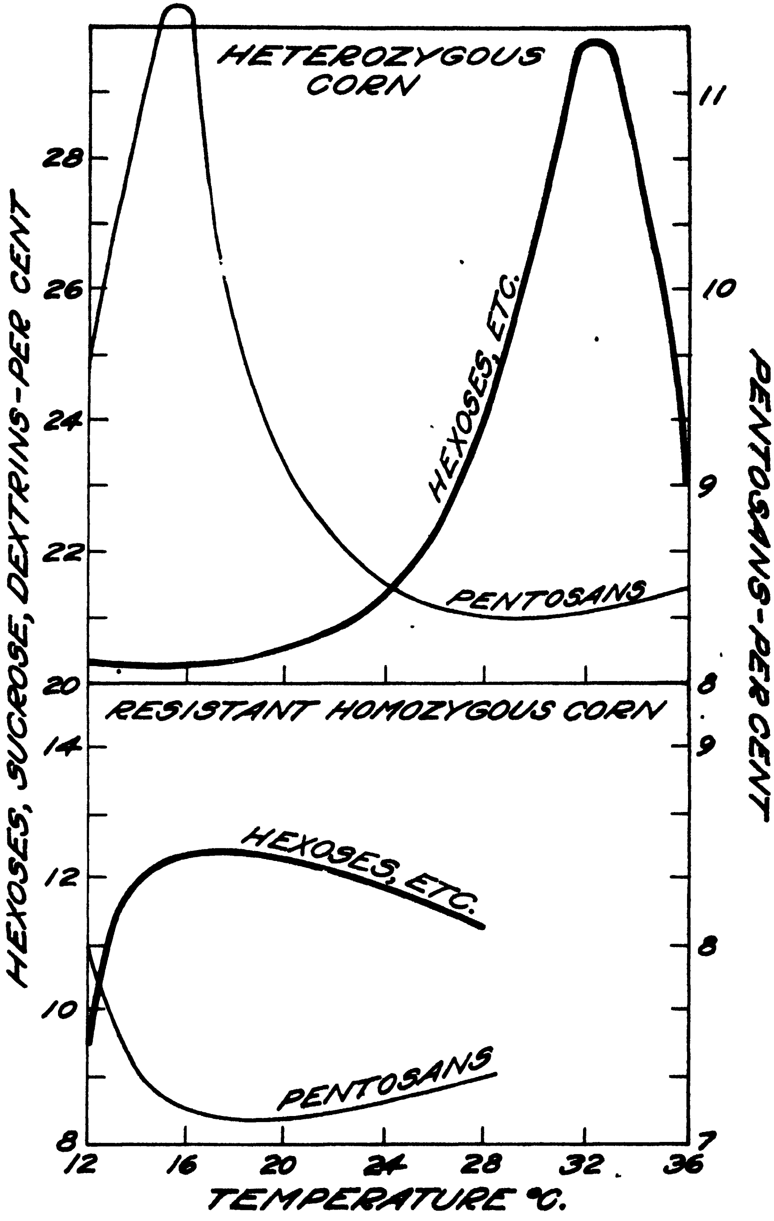

FIG. 3.—Curves showing the influence of temperature upon the composition of open-pollinated corn and a disease-resistant selfed line. The heavy lines represent such carbohydrate building-substances as hexoses, sucrose, and dextrins in the seedling with the endosperm removed. The light lines represent total pentosans contained largely in the cell walls. Note the changes in type of metabolism at the different temperatures as indicated by the relationship of heavy and light lines. These marked changes in the type of metabolism occur at the same temperatures as predisposition to seedling blight. The open-pollinated material blighted below 24°C. and the selfed line blighted at 12°C. and below.

of temperature for each strain. The experiments show further that this temperature response varies from that of strains which are resistant to seedling blight at temperatures from 32° to 12°C., to that of strains which are susceptible at all these temperatures. Both of these strains germinate and grow in a clean soil at temperatures as low as 10°C. Finally, these temperature studies have shown that the first-generation hybrids between these resistant and susceptible strains are susceptible to seedling blight at all temperatures. That is, susceptibility is dominant in such crosses. These results immediately challenge a further genetical, physiological, and chemical study of the nature of this resistance.

The metabolism of the disease-resistant strains is remarkably similar to the mean of that for the open-pollinated corn. The open-pollinated corn was low in hexose and soluble, polysaccharide building-substances below 24°C , with a rapid rise above this temperature and subsequent drop above 32°C. The curve for total pentosan content was just the reverse of this soluble-carbohydrate curve (See upper graph of Fig. 3.) The resistant selfed strain was low in building substances below 12°C., with a rapid rise to the highest plane at 16°C. The curve for total pentosan content again was just the reverse of this curve. (See lower graph in Fig. 3.) These marked changes in metabolism occur at the same temperatures as predisposition to disease. The mean of the open-pollinated material blighted below 24°C., whereas the selfed line blighted at 12°C. and below.

The composition of the resistant strains is comparable to that of the open-pollinated corn. The curve for nitrogen content and its relation to total carbohydrates has a similar trend to that of the open-pollinated seedlings. Likewise, the curves for reducing sugars and sucrose are similar. In each instance, however, the marked changes occur between 12° and 16°C. in the resistant selfed material instead of at about 24°C. as in the open-pollinated plants. The resistant strains, therefore, appear to have a metabolism similar to that of the open-pollinated corn but stabilized and extended over a greater temperature range (Fig. 3). This metabolic balance is directly correlated with predisposition to seedling blight in so far as temperature is a factor influencing the processes. Therefore, it would seem logical to believe that the expression of disease resistance is directly dependent upon host metabolism. The problem is complicated further, however, when the metabolism of the disease-susceptible strains is taken into consideration.

The metabolism of the strains susceptible to disease at all temperatures is significantly different from that of either the resistant strains.

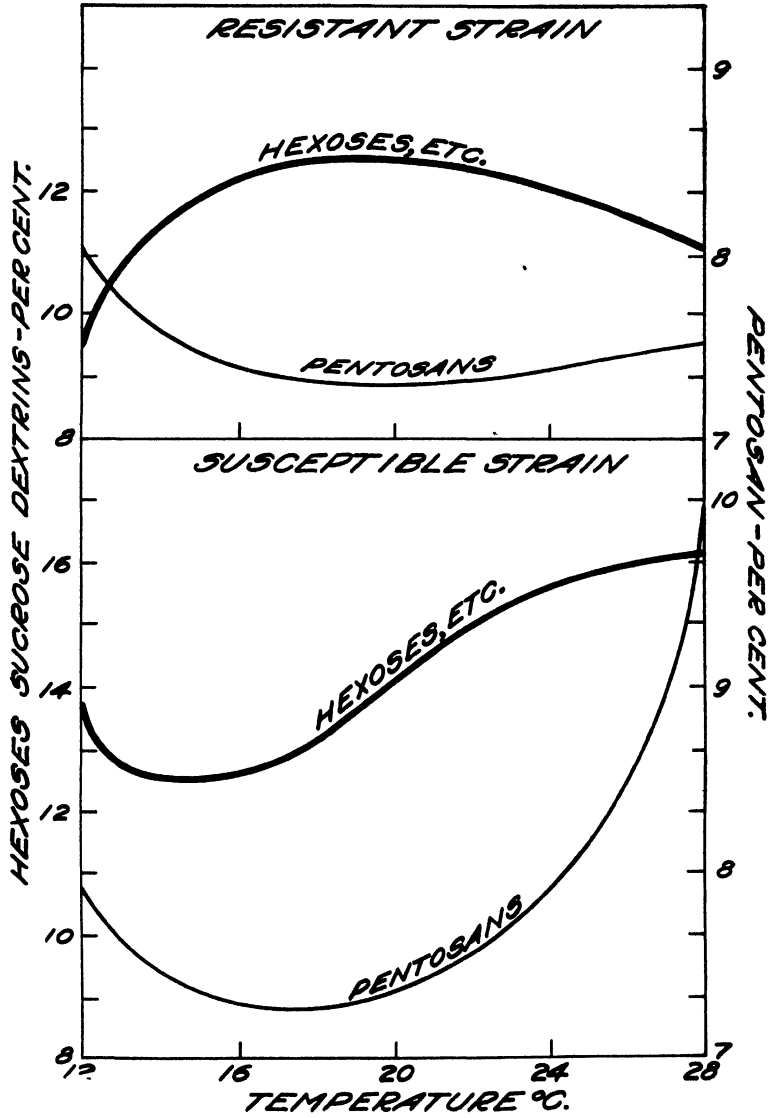

FIG. 4.—Curves showing the influence of temperature upon the composition of resistant and susceptible selfed lines of corn. The heavy lines represent such carbohydrate building-substances as hexoses, sucrose, and dextrins in the seedling with the endosperm removed. The light lines represent total pentosans contained largely in the cell walls. Note the difference in trend of the heavy and light lines in the susceptible strain, indicating an entirely different type of metabolism from that of the open-pollinated corn and the resistant strain.

or the open-pollinated corn. The soluble, carbohydrate building-substances increase with the rise in temperature, due to an accumulation of reducing sugars. (See lower graph of Fig. 4.) There also is a decrease in sucrose content in the susceptible strain with the rise in temperature, whereas in both the resistant strain and open-pollinated corn there is a marked rise in the sucrose content. The pentosan content of the susceptible strain drops at 16°C., then rises abnormally with the rise in temperature, indicating easily hydrolyzable cell walls even at the high temperatures. Microscopic examination of the protective sheath tissues shows these cell walls to be intermediate cellulose compounds with little or no impregnation of the walls with suberin, which was found so abundantly in the cortical cell walls of the resistant strains.

The metabolic balance of the susceptible strains is entirely different from that of the resistant strains, and, as a result, the seedlings are susceptible at all temperatures. The explanation of this susceptibility seems to be an unbalanced metabolism, due to some deficiency in the genetic constitution that affects the chemical composition of the plant. This genetic constitution is dominant in first-generation hybrids between the susceptible and the resistant strains. A detailed study of the second-generation hybrids and back crosses undoubtedly will give more information as to the nature of the susceptibility of these strains.

4. SOME DIFFERENCES IN THE FUNCTIONING OF SELFED LINES OF CORN UNDER VARYING NUTRITIONAL CONDITIONS[1]

G. N. HOFFER[2]

Over six thousand selfed lines of corn have been produced and tested in the experimental corn-breeding plats at LaFayette, Ind., during the past six years.[3] They have been isolated from various strains of Reid Yellow Dent, Johnson County White, Early Yellow

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[1] Paper read as a part of the symposium on "The Present Status of Corn Improvement" at the meeting of the Society held in Chicago, Ill., November 17, 1925.

[2] Pathologist and Agent, Office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, and Associate Botanist, Purdue University Agricultural Experiment Station, LaFayette, Ind., cooperating.

[3] This work is being conducted by the Purdue University Agricultural Experiment Station with the cooperation of the Office of Cereal Investigations of the U. S. Department of Agriculture.

Dent, and commercially used sweet corn varieties.[4] Additional selfed lines have been supplied by corn breeders from other parts of the corn belt.

The most outstanding phenomena noted in the study of these selfed lines are the differences in the rates and extents of growth of many of them when planted in two or more different types of soil. In a given soil some of the selfed lines are superior to others which were derived from the same original seed stock, while in another soil type these growth responses frequently are reversed.

The very irregular growths of corn plants in fields of low fertility are a matter of common observation. Some plants are always found to be relatively vigorous, while others remain more or less stunted and fail to complete their life cycles. In adjacent fields, or perhaps in other parts of the same field, these irregularities of growth are not so prominent, even though the same seed stock may have been used. These irregular growths of open-pollinated strains of corn in fields of low fertility, and the widely variable growths of the selfed lines in experimental breeding plats, present problems of great importance since the average yield per acre in any one of the corn belt states does not exceed 40 bushels.

It is believed that the solution of some of these problems will be found in a study of the nutritional requirements of different strains of corn, and particularly so of the selfed lines which are being isolated at many points in the corn belt to be used in the synthetic production of new strains.

This paper considers some results obtained in experiments using selfed lines and recombinations. The results are not presented as conclusive, but as a report of progress to this symposium.

GENERAL STATEMENT

The nutrition experiments were begun in 1921. Because most of the selfed lines were then only in their second and third generations, it was believed that better results would be obtained, in the preliminary work at least, if selfed lines, first-generation crosses, and double crosses produced by more intensive breeding were used. These were supplied by Dr. D. F. Jones of the Connecticut Agricultural Experiment Station. His single-crossed Leaming, single-crossed Burr-White, and double-crossed Burr-Leaming have been used in practically all of the experiments to date. These strains are used to compare the performances of the selfed lines and the trial crosses produced in the corn breeding experiments at LaFayette.

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[4] B. H. Duddleston, Agronomist, J. F. Trost, Associate Pathologist, and G. M. Smith, Assistant Pathologist, supplied selfed lines of Reid Yellow Dent, Johnson County White, and Early Yellow Dent, and of the sweet corn varieties, respectively, reported in this paper.

Hoffer and Trost (2, 4)[5] already have reported on some of the results obtained with Jones' strains. They were grown in a series of temperature tanks containing triplicate sets of pots of washed sand supplied with a basic nutrient solution and other sets in which the contents of phosphorus and potassium salts were reduced, respectively, to one-tenth that of the basic solution. It was found in these experiments that these strains varied considerably in their relative susceptibilities to a rot of the roots caused by *Gibberella saubinetii* (Mont.) Sacc. The Burr-Leaming was most susceptible when grown with deficient phosphates, being reduced 55.6 % in dry weight when inoculated with this fungus. The single-crossed Leaming was reduced 51.3 % when grown with deficient potassium, while Burr-Leaming double cross was reduced 43.8 % when inoculated. The single-crossed Burr-White was the most resistant under the deficiency of either phosphorus or potassium.

These results showed that some strains have a greater resistance than others to root rot under malnutrition conditions. They also pointed to the possibility of explaining the variations in the sizes of plants in fields of low fertility in which, seemingly, the damages due to various root rots are most severe.

Garrard (3), working at Purdue University Agricultural Experiment Station under the fellowship provided by the National Fertilizer Association, also used Jones' hybrids in his experiments. He showed that the growth and production of dry matter by these strains were directly proportional to the supply of available phosphates. The soil which he used was deficient in phosphorus and was selected because the losses due to root rots are heavy in this soil and others in a similar state of fertility.

By inoculating duplicate series of pots with *G. saubinetii*, Garrard obtained infections of the roots of the plants in both series, but this retarded growth only in the pots without added phosphates. The addition of phosphates to the soil increased the growth rates of the plants, so that, at the temperatures and moisture contents he used, the growth responses were practically the same in both the inoculated and uninoculated pots.

The most important soil deficiencies in Indiana are either phosphates or potash. Consequently, when possible, it has proved highly advantageous to attempt to grow the selfed lines in such soils in order to detect the superior ones and eliminate naturally the physiologically weaker and the root-rot-susceptible lines. This really happens, and so few are left at times as to be almost discouraging, particularly so with the sweet corn varieties.

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[5] Reference by number is to "Literature Cited," p. 334.

The selfed lines which do grow under these adverse soil conditions and withstand these influences predisposing them to become rotted, are naturally superior strains, if otherwise normal in character. Consequently, it is believed that if some rapid means of eliminating the physiologically weak selfed lines among the hundreds produced each year could be developed for use in the greenhouse and laboratory, this means of detection would save time and space in the field. Experiments for this purpose have been conducted with many selfed lines and certain of the results are reported herein.

EXPERIMENTAL

RELATIVE GROWTHS OF 13 SELFED LINES IN A CLAY AND A LOAM

Thirteen selfed lines, most of them in the fourth generation, were planted in alternating soil beds of a slightly acid clay and a neutral loam in the greenhouse. Thirty kernels of each line were planted in each soil in rows 3 inches apart. The soils were uniformly watered throughout the five weeks of the test. At the end of this period the plants of each selfed line were carefully cut just above the soil and dried to constant weight for comparison. The dry weights in grams per plant for each selfed line are given in Table 1 and shown graphically in Fig. 1.

TABLE 1.—*Average dry weight per plant based on 30 plants in each of 13 selfed lines grown in both a slightly acid clay and a loam soil in an experimental greenhouse and harvested February 19, 1924.*

Pedigree numbers	Grams of dry weight per plant grown in	
	Clay	Loam
Trost EYD 51-30-1-6-1	0.118	0.106
Richey Lanc. Co. Sure Crop 2-6-2-1-2[a]	0.117	0.109
Trost EYD 76-10-1-3	0.107	0.087
Trost EYD 46-12-1-10	0.106	0.092
Trost EYD 68-15-1-4-2	0.100	0.092
Trost EYD 6-13-2-3-1	0.098	0.080
Trost EYD 62-15-1-3	0.094	0.078
Trost EYD 54-14-2-1-4	0.094	0.077
Trost EYD 4-3-2-1-1	0.084	0.086
Trost EYD 58-9-2-1-2	0.084	0.076
Trost EYD 75-3-3-1	0.080	0.087
Trost EYD 8-21-1-4	0.062	0.049
Trost EYD 8-21-1-1	0.055	0.048

[a] This selfed line was supplied by F. D. Richey, Office of Cereal Investigations U. S. Department of Agriculture.

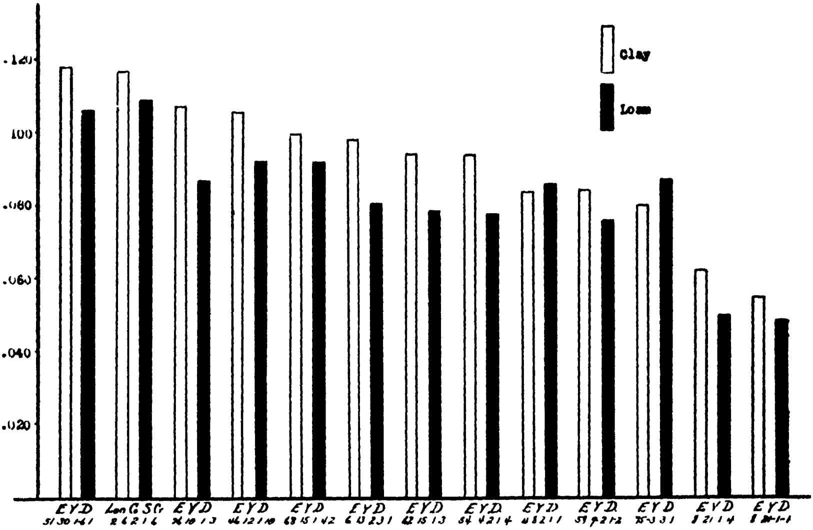

FIG. 1.—Average dry weights per plant of 13 selfed lines of Early Yellow Dent grown in both a clay and a loam soil. Each graph represents 30 plants. Weights given in grams.

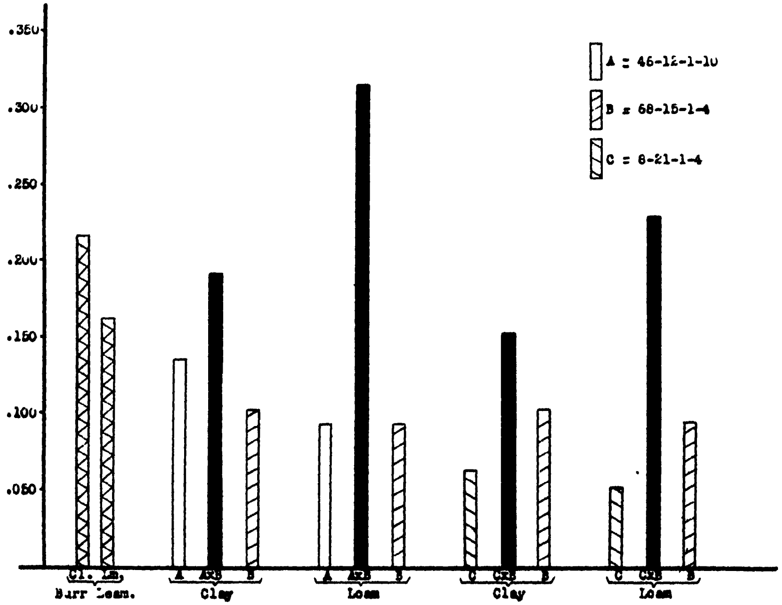

FIG. 2.—Comparative dry weights in grams of the tops of plants of Burr-Leaming, three selfed lines of Early Yellow Dent, and two trial crosses, grown in both a clay and a loam soil in the greenhouse.

The selfed lines are arranged in Table 1, and presented graphically in Fig. 1, in the order of their relative yields of dry matter in the clay soil. Most of the selfed lines grew better in the clay than in the loam. Selfed line E Y D 75–3–3–1, however, has repeatedly made better growth in loam than in clay.

COMPARISON OF RELATIVE GROWTHS OF BURR-LEAMING, THREE EARLY YELLOW DENT SELFED LINES, AND TWO TRIAL CROSSES IN A CLAY AND A LOAM

In this experiment the same soils were used as in the preceding experiment. Burr-Leaming was planted along with Trost's Early Yellow Dent 46–12–1–10, 8–21–1–4, and 68–15–1–4, and two trial crosses among them, using 68–15–1–4 as the pollen parent in both crosses. These strains were grown under conditions similar to those in the preceding experiment. They were harvested at the end of five weeks and the tops of the plants of each strain were dried to constant weights. The results are given in Table 2 and shown graphically in Fig. 2.

TABLE 2.—*Total number of plants and average dry weight per plant of Burr-Leaming, three selfed lines of Early Yellow Dent, and two trial crosses grown both in a clay and a loam in an experimental greenhouse and harvested in February, 1925.*

	Clay			Loam		
Pedigree numbers	Number of plants	Total dry weight in grams	Average dry weight in grams	Number of plants	Total dry weight in grams	Average dry weight in grams.
Jones Burr-Leaming.....	30	6.49	0.216	30	4.85	0.162
Trost Early Yellow Dent 8–21–1–4	89	5.52	0.062	55	2.71	0.049
Trost F₁ Early Yellow Dent 8–21–1–4 x 68–15–1–4.............	30	4.55	0.152	30	6.83	0.228
Trost Early Yellow Dent 68–15–1–4	27	2.70	0.100	28	2.57	0.092
Trost Early Yellow Dent 46–12–1–10..........	37	4.91	0.133	37	3.40	0.092
Trost F₁ Early Yellow Dent 46–12–1–10 x 68–15–1–4..............	30	5.68	0.189	30	9.44	0.315

These dry weights serve as a means of comparing the growths of Burr-Leaming with the trial crosses of Early Yellow Dent. Of particular interest are the relatively better growths of the parent selfed lines of Early Yellow Dent in the clay than in the loam, while the trial crosses grew better in the loam than in the clay. Why these differences occur seemed to be a good problem and, as an

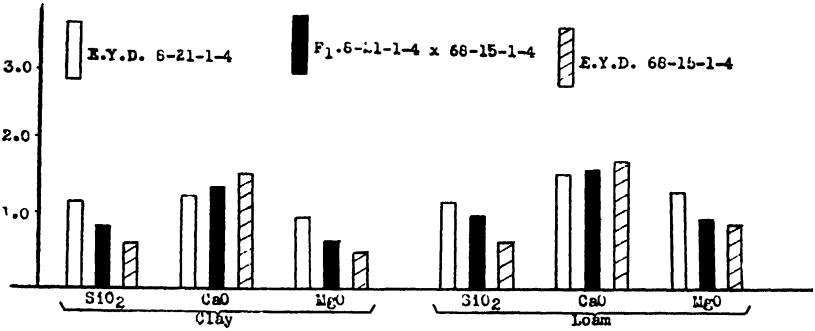

FIG. 3.—Percentage quantity of silicon, calcium, and magnesium as oxides in the dry matter of a hybrid and its parent selfed lines of Early Yellow Dent.

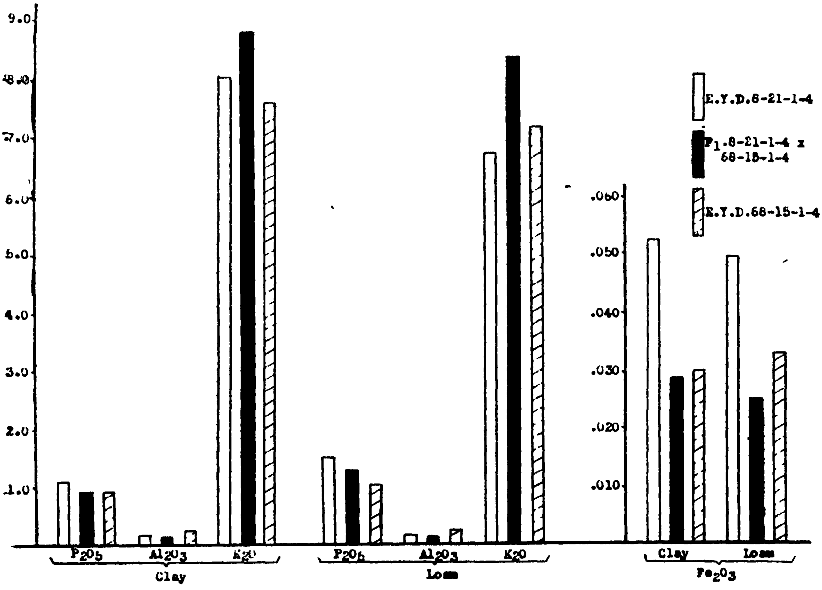

FIG. 4.—Percentage quantity of phosphorus, aluminum, potassium, and iron in the dry matter of a hybrid and its parent selfed lines of Early Yellow Dent.

approach to it, the plants of the EYD selfed lines 8–21–1–4, 68–15–1–4, and the cross between them, grown in both soils, were analyzed for the composition of the ash of their respective dry matters.

The results of these analyses, which were made by R. A. Weaver, analyst in the research chemical laboratory of the Experiment Station, are given in Table 3 and shown graphically in Figs. 3 and 4.

It is evident (Figs. 3 and 4) that the percentage composition of the ash differs markedly in the different lines and crosses. Moreover,

TABLE 3.—*Total number of plants for each strain, total dry weights, average dry weights per plant, and content of total ash and of the ash constituents in percentages of dry matter of tops of young plants of two selfed lines and a cross grown in a clay and a loam in the experimental greenhouse. LaFayette, Ind., in March, 1925.*

Pedigree number	Number of plants	Total dry weight Grams	Average weight Grams	Total ash %	Ash constituents						
					SiO_2 %	P_2O_5 %	Fe_2O_3 %	Al_2O_3 %	CaO %	MgO %	K_2O %
		Clay									
E. Y. D. 8–21–1–4	93	5.52	0.059	17.41	1.20	1.09	0.053	0.17	1.28	0.97	8.17
E. Y. D. 68–15–1–4	27	2.70	0.100	14.55	0.63	0.94	0.030	0.23	1.60	0.50	7.71
F_1 8–21–1–4 x 68–15–1–4	30	4.55	0.152	16.89	0.82	0.91	0.029	0.15	1.38	0.64	8.94
		Loam									
E. Y. D. 8–21–1–4	55	2.71	0.049	15.57	1.20	1.52	0.050	0.19	1.60	1.35	6.82
E. Y. D. 68–15–1–4	28	2.57	0.092	14.40	0.63	1.03	0.033	0.24	1.78	0.94	7.25
F_1 8–21–1–4 x 68–15–1–4	30	6.83	0.228	17.26	1.03	1.30	0.025	0.10	1.66	0.98	8.52

for many of the constituents, the percentage amount in the hybrid is intermediate between those in the parents. Exceptions occur in the case of the iron, aluminum, and potassium. The percentages of iron oxide and aluminum oxide are strikingly lower in the hybrid than in either of the parents, and the quantity of potassium oxide is greater than that in either of the parents. This relation exists in the plants grown in both soils.

The problem which arises from these results is whether or not the increased vigor of the hybrid results from a depression of the absorption of the deleterious iron and aluminum salts. In this particular case, Trost's Early Yellow Dent 8–21–1–4 is a selfed line which is very susceptible to root rots. It has constantly been characterized by heavy iron accumulations in the tissues and serves as an excellent parent to use for trial crosses with other strains in determining certain of these relations in ash composition.

In this connection it should be stated that Hoffer and Trost (2) already have reported on the control of the iron and aluminum injuries to corn previously described by Hoffer and Carr (1). In these two papers it was shown that the aluminum injuries were most severe in plants inadequately supplied with available phosphates, and that the iron accumulations were greatest when potassium salts were lacking or relatively unavailable to the plants.

It is particularly interesting to have the results of these two recent experiments show that there is a definite potassium-iron relationship within the plant which is associated with hybrid vigor and increased resistance to root rot in these strains which have been studied.

COMPARISON OF TWO SELFED LINES OF REID YELLOW DENT WITH NORMAL LEAVES AND TWO WITH DEFECTIVE LEAVES

A study of the ash constituents of the leaves of four selfed lines of Reid Yellow Dent was made in order to determine what differences in the composition of the ash occur in leaves showing certain common defects.

Four selfed lines isolated by B. H. Duddleston from Reid Yellow Dent were selected for analysis. The leaves on the plants representing two of these selfed lines, Troyer 9–1–1–6–1 and Troyer 9–1–1–6–2, were normal in all respects. The leaves of selfed line Mundell 2–1–1–12–2 were characterized by a "dying-between-the-veins." This type of streak is very similar to the streaks produced artificially by injecting stalks with aqueous solutions of various aluminum salts as reported by Hoffer and Carr (1). The leaves from the

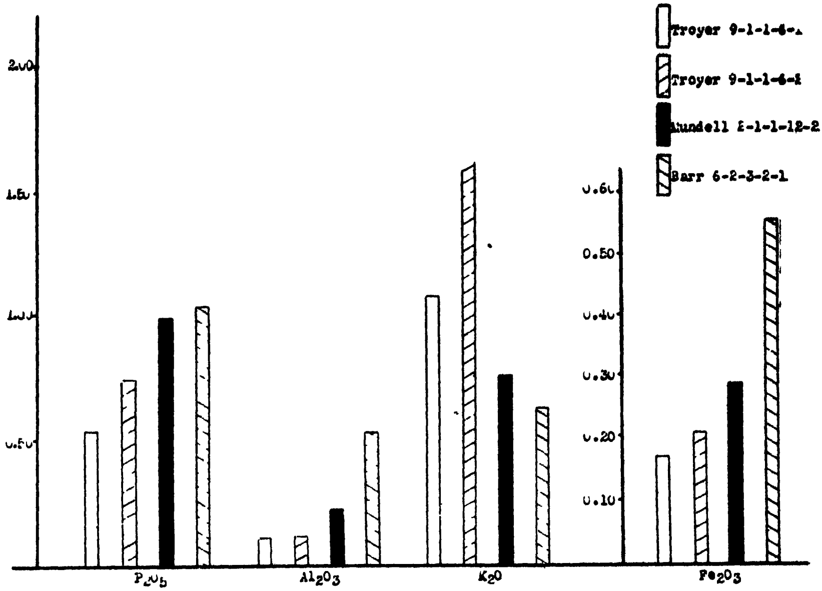

FIG. 5.—Comparative percentage quantities of phosphorus, aluminum, potassium, and iron as oxides in the dry matter of the leaves of four selfed lines of Reid Yellow Dent.

plants of the fourth selfed line, Barr 6–2–3–2–1, were "fired" and taken from plants which had died prematurely. These collections were made on September 24, 1924, from plants which had been grown in an experimental ear-row breeding plat at LaFayette, Ind. The results of the analyses are given in Table 4.

TABLE 4.—*Comparison of the contents of phosphorus, aluminum, potassium, and iron as oxides given in percentages of the dry matter of the leaves of four selfed lines of Reid Yellow Dent grown at LaFayette, Ind., in the summer of 1924.*

Pedigree numbers	Leaf condition	P_2O_5	Al_2O_3	K_2O	Fe_2O_3
		%	%	%	%
Troyer 9–1–1–6–1	Normal	0.54	0.10	1.09	0.017
Troyer 9–1–1–6–2	Normal	0.75	0.11	1.63	0.021
Mundell 2–1–1–12–2	Streaked	1.00	0.22	0.76	0.029
Barr 6–2–3–2–1	Fired	1.04	0.53	0.63	0.056

The chief interest in these ash determinations at present lies in the high iron and aluminum contents of the dry matter of the streaked and prematurely dead leaves of the Mundell 2–1–1–12–2 and Barr 6–2–3–2–1 selfed lines, respectively, as shown in Fig. 5. The iron content of the defective leaves was 53 and 195 % higher, respectively, for these strains than the average content of the normal leaves from the two Troyer selfed lines. The aluminum contents of the dry

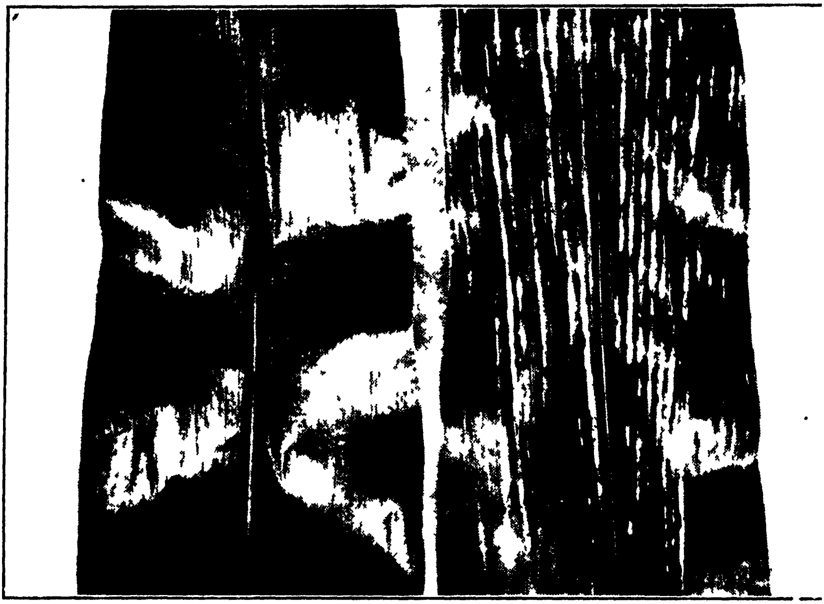

FIG. 6 — A normal leaf and one showing the heritable type of "dying-between-the-veins" from Jenkins' back cross No. 676.

matter of the defective leaves were 109 and 404 % higher than that of the normal leaves Again, it is shown that the deleterious metal ions are the causative agents in the rapid breakdown of the tissues which result in the symptoms of "leaf-streak" of the "dying-between-veins" type and "firing" of the leaves

COMPARISON OF THE PHOSPHORUS, IRON, AND ALUMINUM CONTENTS OF THE DRY MATTER OF NORMAL AND STREAKED LEAVES

This experiment consisted in a comparative study of streaked and normal leaves selected from a five-year selfed line, a back cross, an F_2, and an F_4 generation of two Iowa strains isolated and furnished by M. T. Jenkins of the Office of Cereal Investigations, working in cooperation with the Iowa Agricultural Experiment Station at Ames, Iowa. These lines were planted in the experimental breeding plats at LaFayette, Ind., during the season of 1924. The type of streaking of the leaves is described as a "dying-between-the-veins" and is shown in Fig. 6. Segregation for streaked and normal leaves occurred during the latter part of July, and the leaves were selected for analysis on July 24, 1924.

For the chemical determinations, ten representative leaves

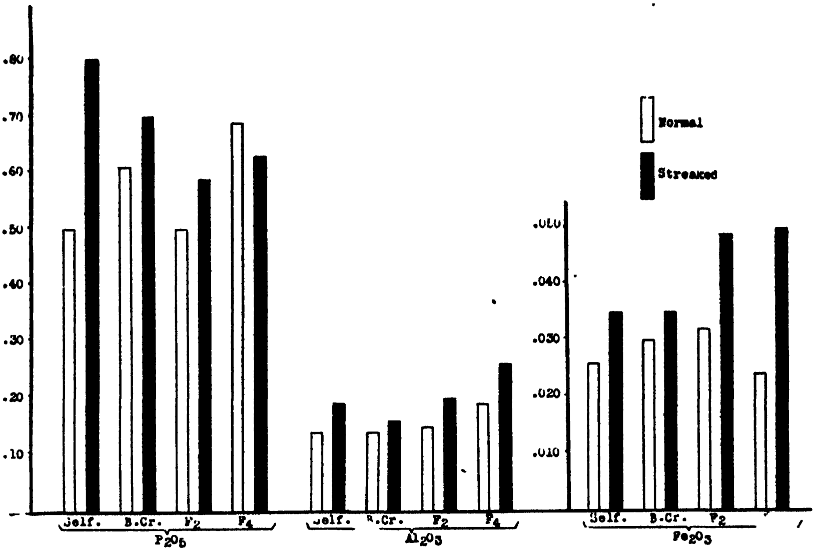

FIG. 7.—Relative percentages of phosphorus, aluminum, and iron calculated as oxides in the dry matter of both normal and streaked leaves of M. T. Jenkins' selfed lines and backcross.

of each type were cut from as many different plants in each of the parallel rows in the same plat. The results of the analyses are given in Table 5 and shown graphically in Fig. 7, Jenkins' original pedigree numbers being used for identification.

TABLE 5.—*Comparison of the contents of phosphorus, aluminum, and iron given as percentages of the dry matter of streaked and normal leaves from Jenkins' selfed lines and back cross.*

Pedigree numbers	Normal leaves P_2O_5 %	Normal leaves Al_2O_3 %	Normal leaves Fe_2O_3 %	Streaked leaves P_2O_5 %	Streaked leaves Al_2O_3 %	Streaked leaves Fe_2O_3 %
Jenkins 617—selfed line	0.50	0.14	0.026	0.80	0.19	0.035
Jenkins 676—back cross	0.61	0.14	0.030	0.70	0.16	0.035
Jenkins 683—F_2 generation	0.58	0.15	0.032	0.59	0.20	0.049
Jenkins 684—F_4 generation	0.69	0.19	0.024	0.63	0.26	0.050
Average composition	0.595	0.155	0.028	0.68	0.202	0.042
Relative average composition	100	100	100	114	130	150

The analyses of this plant material as shown in Fig. 7 supply good evidence that the tendencies to absorb iron and aluminum salts in different quantities from the soil are due to heritable characters in the selfed lines. The average contents of aluminum and iron in the dry matter of these streaked leaves are 30 and 50 % higher than the amounts present in the dry matter of normal leaves. These differences are of significance and it is believed that they reflect different abilities of these strains to resist the entry of deleterious substances into the plant structures.

SUMMARY

The results of these experiments show that the absorption abilities of selfed lines and of crosses between them vary widely with respect to certain of the essential mineral nutrients and to the iron and aluminum salts in the soil solution.

The quantities of certain of the ash constituents absorbed by the hybrids are intermediate between the amounts absorbed by the parent selfed lines, while iron and aluminum are absorbed in lesser quantities by the hybrids than by either of the parent lines.

Less iron and aluminum are absorbed by the hybrid in loam than in clay. These differences are inversely related to the increased growth as shown by the dry weights of the plants in both soils. Associated then with hybrid vigor are absorption tendencies of the plants which result in less amounts of iron and aluminum being absorbed by the vigorous hybrid than by either of the parents of less vigorous growth.

The heritable tendencies of certain selfed lines to have the leaves develop a "dying-between-the-veins" type of injury are associated with a relatively higher percentage content of iron and aluminum in the dry matter of these leaves than in the normal leaves of each generation.

These relations point to heritable differences between selfed lines with respect to their absorption capacities for nutrient and non-essential elements that are present in available forms in the soil solution. These differences are most prominent in soils of low fertility. They are associated with different rates of growth of the plants and their relative resistance to root rot.

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5. THE COMPARATIVE WATER ECONOMY OF SELFED LINES OF CORN AND THEIR HYBRIDS[1]

T. A. KIESSELBACH[2]

OBJECT

The transpiration studies reported in this paper have been conducted at the Nebraska Agricultural Experiment Station supplementary to field experiments with selfed lines of corn and various hybrid recombinations thereof. Their purpose has been to indicate the relation of heterozygosity to the water economy of corn, and to suggest the variability in this regard which may be expected between different selfed lines and hybrids. The results of these tests have been summarized in seven accompanying tables. The first three of these report the data for selfed lines and hybrids of Hogue Yellow Dent corn grown in potometers in 1924. The next three tables report similar data for Nebraska White Prize corn grown during 1923 and 1924. The seventh table averages three years' results with 13 F_1 hybrids between selfed lines of Hogue Yellow Dent corn tested during 1916, 1917, and 1919.

METHODS

Individual corn plants were grown to normal maturity in large, galvanized iron potometers 36 inches deep and 16 inches in diameter. These were situated in excavations in the corn field with their tops level with the adjacent land.

The soil moisture supply was maintained fairly uniform by keeping a constant supply of water in the jars connected at the base of the potometers. Rainfall was excluded and evaporation was reduced to a negligible amount through the use of a modeling clay seal and a 3-inch gravel mulch as described in Nebraska Research Bul. 6. The water used by the crop was determined from the difference in initial and final weight of the potometer and from the net water supplied during growth.

The inbred strains were assembled in one group surrounded in the field by inbred corn, whereas the hybrids were grouped 30 yards distant and were surrounded by hybrid corn. This arrangement afforded normal wind protection.

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[1] Paper read as a part of the symposium on "The Present Status of Corn Improvement" at the meeting of the Society held in Chicago, Ill., November 17, 1925. Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, as Paper No. 18, Journal Series. Published with the approval of the Director.

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Tests were replicated 8 to 16 times during 1923 and 1924 and 4 times in earlier years.

The potometer equipment employed has not been developed especially for these investigations, but has been used during the last 14 years in a comparative study of varietal and environmental factors in relation to the water requirements of crops.

The original seed stocks grown each year in potometers as a check yielded at the rate of 75 bushels per acre as an average during the five years of these tests, assuming a field stand of 2½ plants per hill, spaced 42 inches apart. This is evidence of normal development.

HOGUE YELLOW DENT SELFED LINES AND HYBRIDS

The comparative growth and water requirement ratios were determined in 1924 for (a) eight selfed lines which had been inbred for at least 12 years; (b) four F_1 single crosses in which all eight selfed lines were involved; (c) four F_2 single crosses having the same parentage as the F_1 single crosses; (d) two F_1 double crosses; and (e) one F_1 double double cross involving all eight selfed lines.

Rather consistent with normal field behavior, the yield of the selfed lines was far below that of the original commercial variety. The yield of the various F_1 hybrids averaged far greater than the selfed lines due to heterosis, while the F_2 hybrids were intermediate as was to be expected.

EFFECT OF HETEROSIS ON TRANSPIRATION

The relation of heterozygosity can be best indicated by comparing averages of the various selfed lines and hybrids since the inheritance of all eight strains is then represented in each average (Table 1).

The inbreds, F_2 hybrids, and F_1 hybrids averaged, respectively, 639, 491, and 419 grams of water used per gram of ear corn and 274, 244, and 232 grams water per gram of total dry matter. The F_1 single crosses, F_1 double crosses, and F_1 double double cross were in rather close agreement in their water requirement ratios and averaged somewhat lower than the original corn.

VARIABILITY OF SELFED LINES AND HYBRIDS

Selfed lines.—Comparing the various selfed lines (Table 2), these are seen to have varied from 42.5 kilograms to 85 kilograms water transpired per plant. The extreme variation in amount of water transpired per gram dry matter was from 249 to 305 grams and per gram ear-corn from 448 to 1,013 grams.

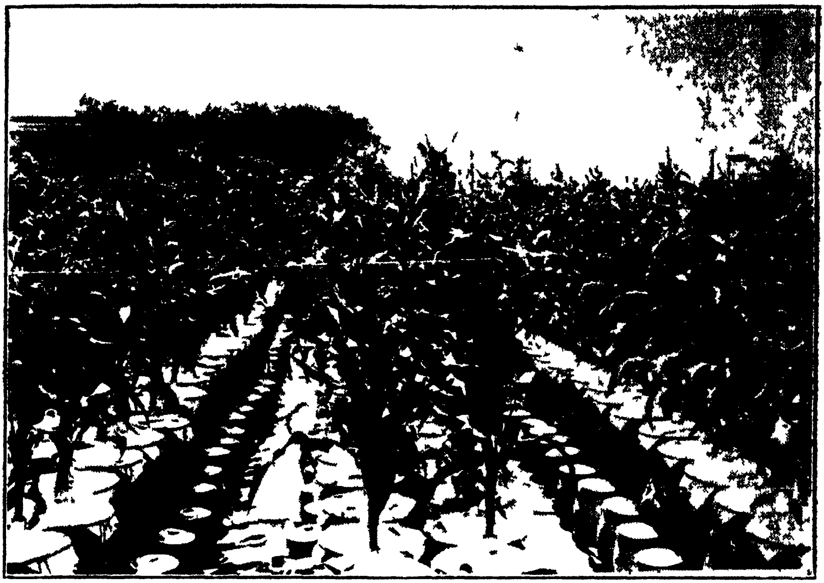

Fig 1 — Selfed lines of Hogue Yellow Dent and Nebraska White Prize corn being tested in the corn field for their transpiration relationships in 1924 Eight potometers were planted to each line

Fig. 2.—Hybrids between selfed lines of Nebraska White Prize corn being tested in the corn field for their transpiration relationships in 1924 The Hogue

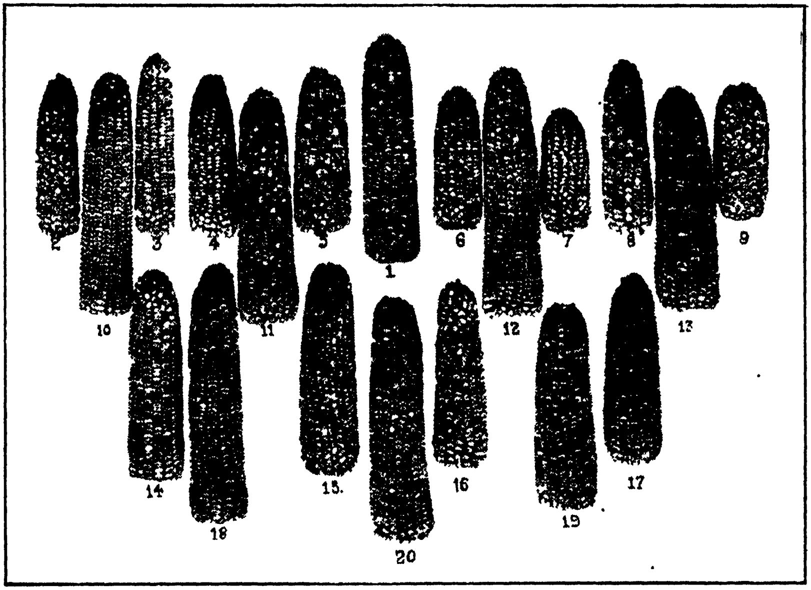

FIG. 3.– Representative ears of selfed lines and hybrids of Hogue Yellow Dent, corn grown in potometers in 1924.

1, Original Hogue variety; 2-9, Selfed lines; 10-13, F_1 single hybrids; 14-17 F_2 hybrids; 18 and 19, F_1 double hybrids; 20, F_1 double x double cross

Selfed lines: 2 = Stock No. 1; 3 = Stock No. 12; 14 = No. 724; 5 = No. 742; 6 = No. 725; 7 = No. 723; 8 = No. 751; 9 = No. 733.

F_1 single crosses: 10 = 1 x 12; 11 = 724 x 742; 12 = 725 x 723; 13 = 751 x 733.

F_2 single crosses: 14 = 1 x 12; 15 = 724 x 742; 16 = 725 x 723; 17 = 751 x 733.

F_1 double crosses: 18 = (1 x 12) x (724 x 742); 19 = (725 x 723) x (751 x 733).

F_1 double x double cross: 20 = (2 x 1) (724 x 742) x (725 x 723) (751 x 733).

TABLE 1.—*Growth and water requirements of selfed lines of Hogue Yellow Dent corn and of various hybrid combinations thereof in 1924.*

Description	Number of strains or hybrids	Total number of pots	Dry matter per plant Ear	Dry matter per plant Total	Leaf area per plant	Transpiration per Plant	Transpiration per Gram dry matter Ear	Transpiration per Gram dry matter Total
			Grams	Grams	Sq. in.	Kilos	Grams	Grams
Selfed lines. .	8	59	103	230	746	61.9	639	274
F_2 hybrids. . . .	4	30	131	273	897	70.8	491	244
F_1 hybrids. . . .	4	28	219	393	1,012	91.5	419	232
F_1 double crosses	2	13	206	387	1,102	87.6	426	226
F_1 double x double.	1	15	212	376	1,008	85.3	402	227
Original.	—	16	235	458	1,239	108.0	461	236

F_1 single crosses.—The F_1 single crosses varied from 70.5 to 115.0 kilograms transpiration per plant, from 213 to 244 grams water per gram total dry matter, and from 365 to 464 grams water per gram ear-corn (Table 3).

F_1 double crosses.—The two F_1 double crosses varied from 85.6 to 89.7 kilograms water transpired per plant and the water requirement ratios varied from 226 to 227 grams water per gram total dry matter and from 393 to 460 grams water per gram ear-corn (Table 3).

NEBRASKA WHITE PRIZE SELFED LINES AND HYBRIDS

Data are averaged for two years in Tables 4 to 6, comparing (a) six selfed lines that have been inbred for at least ten years with (b) three F_1 single crosses in which all six selfed lines were involved, (c) three F_2 single crosses having the same parentage as the F_1 single crosses, and (d) two F_1 double crosses involving all six selfed lines.

TABLE 2.—*Growth and water requirements of selfed lines of Hogue Yellow Dent corn in 1924.*

Stock Nos.	Total number of pots	Dry matter per plant		Leaf area per plant	Transpiration per		
		Ear Grams	Total Grams	Sq. in.	Plant Kilos	Gram dry matter Ear Grams	Total Grams
1	8	123	275	696	69.1	563	255
12	7	99	162	573	44.2	448	286
724	8	148	328	1,390	85.0	573	260
742	8	147	331	1,093	84.0	572	254
725	7	69	171	533	42.5	619	249
723	7	58	201	757	58.9	1,013	293
751	8	115	216	542	63.0	546	292
733	6	62	158	422	48.2	778	305
Average	-	103	230	746	61.9	639	274
Original	16	235	458	1,239	108.0	461	236

Consistent with field behavior, the selfed lines averaged only 36% as much grain yield per plant as the original variety, while the F_1 single and double crosses yielded somewhat more grain than the original. The F_2 hybrids yielded intermediate between the selfed lines and the F_1 hybrids.

EFFECT OF HETEROSIS ON TRANSPIRATION

The selfed lines, F_2 hybrids, and the two forms of F_1 hybrids averaged (Table 4), respectively, 69.3, 90.9, and 114.3 kilos water transpired per plant; 900, 514, and 442 grams water used per gram ear-corn, and 319, 269, and 257 grams water per gram total dry matter. The F_1 single and double crosses averaged nearly alike in their water requirement ratios and differed but little from the original variety.

TABLE 3.- *Growth and water requirements of hybrids between selfed lines of Hogue Yellow Dent corn in 1924.*

Stock Nos.	Total number of pots	Dry matter per plant		Leaf area per plant	Transpiration per		
					Plant	Gram dry matter	
		Ear	Total			Ear	Total
		Grams	Grams	Sq. in.	Kilos	Grams	Grams
		F_1 Single Crosses					
1 x 12	7	229	394	1,014	95.4	417	244
724 x 742	7	248	480	1,358	115.0	464	240
725 x 723	8	165	331	930	70.5	429	213
751 x 733	8	234	369	748	85.2	365	231
Average	—	219	393	1,012	91.5	419	232
		F_2 Single Crosses					
1 x 12	7	148	269	852	74.3	501	276
724 x 742	8	178	372	1,241	91.2	512	245
725 x 723	6	90	221	818	49.1	548	222
751 x 733	7	108	232	679	68.7	403	233
Average	--	131	273	897	70.8	491	244
		F_1 Double Crosses					
(1 x 12) x (724 x 742)	7	195	396	1,260	89.7	460	227
(725 x 723) x (751 x 733)	6	218	379	943	85.6	393	226
Average	—	206	387	1,102	87.6	426	227
		F_1 Double x Double					
8 strains involved	15	212	376	1,008	85.3	402	227
		Original Commercial Seed					
Original	16	235	458	1,239	108	461	236

VARIABILITY OF SELFED LINES AND HYBRIDS

Selfed lines.—The six selfed lines included in these tests varied from 52.8 to 87.6 kilos transpired per plant compared with 111.7 kilos for the original corn (Table 5). The extreme variation in the amount of water transpired per gram of dry matter was 253 to 333 grams compared with 243 for the original. The extreme water requirement ratios for ear-corn production were 503 and 1,432 compared with 470 for the original.

F_1 single crosses.—The F_1 single crosses ranged from 97.9 to 135.4 kilograms water transpired per plant compared with 111.7 kilograms for the original; from 241 to 272 grams water per gram total dry matter compared with 243 for the original; and from 408 to 491 grams per gram of ear-corn compared with 470 grams for the original variety (Table 6).

F_1 double crosses.—The two F_1 double crosses varied from 112.6 to 121.1 kilograms water transpired per plant. The water require-

TABLE 4.—*Growth and water requirements of selfed lines of Nebraska White Prize corn and various hybrid combinations thereof, two years' average, 1923–1924.*

Description	Number of strains or hybrids	Total number of pots for two years	Dry matter per plant		Leaf area per plant	Transpiration[a] per		
			Ear	Total		Plant	Gram dry matter Ear	Total
			Grams	Grams	Sq. in.	Kilos	Grams	Grams
Selfed lines....	6	84	86	224	830	69.3	900.0	319.0
F_2 hybrids....	3	42	178	339	1,122	90.9	514.0	269.0
F_1 hybrids....	3	43	243	429	1,249	111.8	443.0	260.0
F_1 double crosses	2	30	262	461	1,267	116.8	441.0	254.0
Original......	—	27	238	460	1,257	111.7	469.9	242.7

[a] Average of ratios.

TABLE 5.—*Growth and water requirements of selfed lines of Nebraska White Prize corn, average for two years, 1923–1924.*

Stock Nos.	Total number of pots for two years	Dry matter per plant		Leaf area per plant	Transpiration[a] per		
		Ear	Total		Plant	Gram dry matter Ear	Total
		Grams	Grams	Sq. in.	Kilos	Grams	Grams
659	16	106	209	624	52.8	503	253
663	12	80	211	851	67.8	811	322
672	14	123	285	862	87.6	713	308
676	16	88	191	852	60.9	714	322
671	11	57	228	943	72.8	1,432	320
667	15	62	219	851	73.7	1,230	333
Average	—	86	224	830	69.3	900	310
Original	27	238	460	1,257	111.7	470	243

[a] Average of ratios.

ment ratios per pound of dry matter were 253 and 254, while the variation in transpiration per gram ear-corn was from 420 to 461 grams (Table 6).

COMPARATIVE TRANSPIRATION RELATIONSHIPS OF 13 HOGUE YELLOW DENT F_1 SINGLE CROSSES TESTED DURING THREE YEARS

A group of 13 Hogue Yellow Dent F_1 single crosses were compared (Table 7) for their transpiration relationships during the three years 1916, 1917, and 1919. The selfed lines involved had been inbred for five years prior to 1914 when the first hybrid seed was produced. The total water transpired per plant during this period ranged from 87.6 to 136.1 kilograms for the various combinations. These hybrids

TABLE 6.—*Growth and water requirements of hybrids between selfed lines of Nebraska White Prize corn, average for two years, 1923–1924.*

Stock Nos.	Total number of pots for two years	Dry matter per plant Ear	Dry matter per plant Total	Leaf area per plant	Transpiration[a] per Plant	Transpiration[a] per Gram dry matter Ear	Transpiration[a] per Gram dry matter Total
		Grams	Grams	Sq. in.	Kilos	Grams	Grams
		F_1 Single Crosses					
663 x 659	15	249	422	1,111	102.0	408	241
672 x 676	13	204	367	1,200	97.9	430	266
671 x 667	15	276	499	1,437	135.4	491	272
Average	—	243	429	1,249	111.8	443	260
		F_2 Single Crosses					
663 x 659	13	167	316	1,033	86.6	517	274
672 x 676	15	176	329	1,055	87.4	496	267
671 x 667	14	190	371	1,279	98.8	528	267
Average	—	178	339	1,122	90.9	514	269
		F_1 Double Crosses					
(663 x 659) x (672 x 676)	15	260	446	1,267	112.6	420	253
(663 x 659) x (671 x 667)	15	263	476	1,266	121.1	461	254
Average	--	262	461	1,267	116.8	441	254
		Original Commercial Seed					
Original	27	238	460	1,257	111.7	470	243

[a] Average of ratios.

varied from 255 to 307 grams water transpired per gram total dry matter and from 451 to 547 grams water used per gram dry weight of ear-corn.

The data are suggestive of wide variations between different hybrids in the water requirement ratios and in total water used per plant. Doubtless these variations are factors in the adaptedness of corn to various regional and seasonal conditions. In farm practice in regions of relatively unfavorable moisture supply, corn types are commonly grown which use a relatively small amount of water per plant due to small size and early maturity. This difference in total water used is considered a more vital factor in the suitability of corn for drouthy conditions than are the water requirement ratios to dry matter produced.

There doubtless are physiological factors for drouth resistance which cannot be determined without more exhaustive and inclusive physiological investigations than those herein reported.

It is not considered important in the practical improvement of corn for regions of low rainfall that water requirement comparisons

TABLE 7.—*Comparative water requirements of first generation hybrids between selfed lines of Hogue Yellow Dent corn, average for three years, 1916, 1917, and 1919.*

Stock Nos.	Total number of pots	Dry matter per plant Ear	Dry matter per plant Total	Leaf area per Plant	Leaf area per Gram dry matter	Transpiration[a] per Plant	Transpiration[a] per Gram dry matter Ear	Transpiration[a] per Gram dry matter Total
		Grams	Grams	Sq. in.	Sq. in.	Grams	Grams	Grams
Commercial Seed								
Original	12	253	451	997	2.27	118.0	489	269
Hybrids Between High-leaf-area Strains								
724 x 722	12	234	468	1,155	2.53	130.9	578	285
743 x 746	12	293	495	1,098	2.25	131.2	451	270
726 x 741	10	259	481	1,031	2.16	122.3	484	258
745 x 742	12	253	504	1,314	2.64	136.1	551	272
743 x 722	12	204	402	1,042	2.63	107.4	549	274
728 x 746	12	262	472	1,112	2.53	118.7	462	255
Average	—	251	471	1,125	2.46	124.5	513	269
Hybrids Between Low-leaf-area Strains								
756 x 730	12	209	356	752	2.11	106.5	528	307
736 x 754	12	175	331	792	2.40	87.6	512	268
731 x 732	12	239	424	903	2.15	115.9	490	277
738 x 752	11	213	422	908	2.15	112.4	536	271
731 x 736	12	203	385	816	2.14	110.6	547	293
751 x 738	12	238	420	771	1.84	112.7	479	271
731 x 739	12	216	397	744	1.88	107.8	508	276
Average	—	213	391	812	2.10	107.6	514	280

[a] Average of ratios.

of this nature be made. Relative field performance under the conditions where the crop is to be grown is the most certain index now known as to suitability for those conditions.

CONCLUSIONS

A definite relation exists between heterozygosity and the water requirement of corn. Selfed lines which have been reduced in size and productivity by inbreeding have materially higher water requirement ratios than either F_1 hybrids between them or than the original variety from which they were developed.

Second generation hybrids which are also reduced in productivity average somewhat higher water requirement ratios than the F_1 hybrids from which they are produced, though the effect is not nearly so marked as in the case of long continued selfed lines.

From the standpoint of water requirement ratios there is no advantage in having more than two selfed lines recombined into an F_1 hybrid. Using a rather limited number of selfed lines for producing hybrids, greater variability may be expected between the single crosses produced than between crosses involving four or more lines.

Approximately equal efficiency in the use of water is indicated for double crosses and single crosses. The high efficiency of an F_1 hybrid involving eight selfed lines is suggestive that efficient synthetic varieties may also be produced.

Great variability occurs betwen different F_1 hybrids as to productivity, water requirement ratios, and total water transpired per plant.

It is not regarded essential for the development of hybrids suitable for regions subject to drouth that water requirement determinations of this nature be made. The relative field performance under the conditions where the crop is to be grown is doubtless the most certain index as to suitability for those conditions. Relatively low leaf area per plant is suggestive of low total water requirement.

6. PRESENT-DAY PROBLEMS OF CORN BREEDING[1]

H. K. HAYES[2]

From the list of titles for this program, the addresses which have preceded this paper, and from informal discussions of corn improvement which have been held at various meetings of this Society, it is apparent that present-day problems of corn improvement are concerned largely with the reactions of selfed lines and of crosses between them.

The development of the practice of breeding cross-pollinated plants by some method of controlled pollination has been gradual. The method originated as a result of intensive studies of the effects of self-fertilization in cross-pollinated species and throughout this study the work with corn has been of fundamental importance. The studies which were initiated over 15 years ago by Dr. E. M. East at the Connecticut station, at Cold Spring Harbor by Dr. G. H. Shull, and by various workers of the Bureau of Plant Industry and others had as their aim the development of a more intensive knowledge of the physiology of inheritance of the corn plant, with the belief that such studies were essential to the development of better methods of breeding. In 1910, Dr. Shull emphasized the value of isolating pure lines and of using F_1 crosses between pure lines for maximum production. He makes the significant comment that "I feel quite sure that the results of such investigations will lead to some hybridization method in the breeding of this crop."

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[1] Paper read as a part of the symposium on "The Present Status of Corn Improvement" at the meeting of the Society held in Chicago, Ill., November 17, 1925. Published with the approval of the Director as Paper No. 570 of the Journal Series of the Minnesota Agricultural Experiment Station.

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Early in the studies it was recognized that vigor in corn was correlated with the heterozygous condition. Studies in genetics, especially the location of genetic factors in particular chromosomes, have led to an appreciation of the complexity of characters and paved the way for a genetic interpretation of the results of cross and self-fertilization. The present commonly accepted explanation was first made by Dr. D. F. Jones of the Connecticut station (5).[3] According to his hypothesis, the vigor of the first generation cross is the result of the interaction of dominant favorable growth factors some of which are supplied by each of the parent lines. To explain why no selfed line was as vigorous as the normal variety, it was further supposed as a result of linkage that it was very difficult to get all desirable growth factors in one homozygous line.

The placing of the effects of crossing and selfing on a definite genetic basis is one of the main reasons for the general support for the present methods of corn breeding. Perhaps of equal importance is the realization that the limit of progress by the older methods in the majority of cases has been reached. There has been likewise a growing appreciation that with adapted varieties close selection to score-card type, if carefully continued, may lead, and in some cases has led, to a reduction in yielding ability.

While the general method of controlled pollination as a means of isolation of material of known hereditary characters is apparently sound, there are many problems of a research nature which must be solved before the plan of breeding can be entirely standardized. The justification of any breeding plan to the agronomist not actually carrying on the studies must rest rather largely on experimental proof of increased yields, improved quality, or both. The present paper will be developed along two main lines:

1. Experimental results which indicate the value of the present methods of breeding.
2. Some questions of a technical nature which remain to be solved.

1. INCREASED YIELDS BY BREEDING

Since the adoption of the present methods of breeding, many preliminary comparisons of improved sorts and commercial varieties have been made. In spite of the general belief of those actually engaged in corn breeding that real progress in corn improvement will be achieved as a result of these studies, the published data which would justify this belief are very meager. In order to place the position of corn improvement in as favorable a light as it deserves, experiments of various investigators are summarized, although in several cases the data used have not yet been published.

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[3] Reference by number is to "Literature Cited," p. 363.

Before presenting these results a brief summary will be made of the methods used. Numerous plants of a commercial variety are self-pollinated. The seed for each subsequent generation is obtained by self-pollinating plants which seem desirable. The best appearing strains which approach homozygosis are selected for further breeding operations. Three general uses of such strains are being tried out. These are (a) single crosses, (b) double crosses, and (c) synthetic recombination of several selfed strains.

In the single cross plan two selfed strains are crossed and the F_1 generation grown as the commercial crop. Certain difficulties are involved in this. The low yield of seed which is usually obtained from closely inbred lines will result in increased cost of seed production. In many inbred lines the size of seed is smaller than that of the commercial variety from which the inbred line was obtained. This results in some handicap for the young plant when single crosses are used for the commercial crop. With the production of better selfed strains it is possible that the single cross plan may prove more feasible.

The double cross plan, outlined originally by Jones, overcomes some of these difficulties, although instead of making one cross to obtain commercial seed three crosses must be made. A double cross is really a first generation cross between two single crosses. . Four selfed strains which combine well together are used. The double cross plan has the advantage that vigorous F_1 crosses are used as parents. The variability of the individual plants of a double cross will be greater than in a single cross. This will result in a prolonged period of pollination which, under certain environmental conditions, is an advantage.

The production of improved varieties synthetically by a cross of several selfed lines and subsequent selection aims at the improvement of the variety without the necessity of making an F_1 cross each year (3). It appears probable, however, that it will be very difficult to obtain a variety which will be as vigorous as certain F_1 crosses. When a single character, such as disease resistance, is of outstanding importance the plan appears to be a sound one.

RESULTS IN CONNECTICUT

In recent years comparison of F_1 crosses of selfed lines with standard varieties has been made in carefully conducted field trials. Jones has reported a comparison of single and double crosses with commercial Connecticut varieties. The long-time selfed lines, which were originally started by East, continued by the present writer, and later by Jones, were used for these studies. Most of the strains were obtained originally from Illinois varieties and consequently the crosses are not strictly comparable with Connecticut varieties. The more extensive trials in which both single and double crosses and varieties are compared were made in 1919 and 1920.

In general, both the single and double crosses (6), from 1916 to 1920, were higher yielders on the average than the varieties, and the double crosses were somewhat superior to the single crosses. The experiment does not show, however, that certain single crosses may not prove entirely satisfactory from the standpoint of yield. Average increases in yields of bushels of shelled corn of the 10 highest yielding double crosses over the 10 highest yielding varieties were 16.9, 25.6, and 35.3% for the years 1918, 1919, and 1920, respectively.

A double cross, known as Burr-Leaming, has received wide publicity because of its yielding ability. This double cross was compared by Jones with the five highest yielding varieties which were obtained after extensive studies of corn varieties in Connecticut (Table 1). The average increase in bushels of ear-corn of the Burr-Leaming over the average of the five varieties was 27.1 % for a five-year period.

TABLE 1.—*A comparison of the yields in bushels per acre obtained from the double cross Burr-Leaming with the average yields obtained from the five highest yielding varieties.*

Connecticut Station. After Jones.

Varieties compared	Year grown					
	1918 Bushels	1919 Bushels	1920 Bushels	1921 Bushels	1922 Bushels	Average Bushels
Double cross Burr-Leaming.	116	88	55	95	63	83.4
Average of five highest yielding varieties	82	64	47	81	54	65.4

Average increase, 27.1%

Extensive studies are now under way at Connecticut in which selfed lines from the better Connecticut varieties are being used. One double cross studied in 1924 by Jones indicates that large increases in yields may be expected (Table 2).

In this case an F_1 cross of two inbred Century Dent strains was crossed reciprocally with an F_1 of two Leaming strains and the yields of the double crosses were compared with those obtained from Century Dent and Leaming. These studies are of interest for Century Dent and Leaming are two of the best Connecticut varieties. The double cross, Century F_1 x Leaming F_1, exceeded the higher yielding variety by 21.6 % and the reciprocal yielded 37.4 % more than the higher yielding variety.

TABLE 2.—*A comparison of the yields obtained in bushels per acre from Century Dent, Beardsley's Leaming, and a double cross obtained from two inbred strains of Century Dent by two inbred strains of Leaming.*

Connecticut Station. After Jones 1924 results.

Variety or cross	Plat 1	Plat 2	Average	Percentage yield, Century as 100
	Bushels	Bushels	Bushels	%
Century	46.6	50.6	48.6	100.0
Leaming	36.1	51.1	43.6	89.7
Century F_1 x Leaming F_1 ..	63.1	70.6	66.8	137.4
Leaming F_1 x Century F_1 .	51 1	67.1	59 1	121.6

F_1 CROSSES IN TENNESSEE

Several years ago Richey (11) reported the production of a high yielding F_1 hybrid of Whatley x St. Charles White which appeared superior to any commercial variety grown in the region in which the study was made. Selfed lines were isolated from the F_2 generation and selections made within these lines for six years. Crosses between these selfed lines were grown at Knoxville, Tennessee, in 1922 and 1923 (12). The studies were made by the hill check plan. Certain crosses were of much promise, while others were of little value. This brings out the fact, recognized by most investigators of modern methods of corn breeding, that the present-day methods are primarily those of controlled selection. The combination of selfed lines which together contain the greatest number of favorable growth factors is the ultimate aim. Three of the better producing crosses reported by Richey and Mayer (12) averaged 30 % higher in yield than the parent variety.

F_1 CROSSES OF SELFED STRAINS IN NEBRASKA

Extensive studies are being carried on in Nebraska by Kiesselbach (8). The results of a four-year trial of several single crosses in comparison with the original variety have been reported (Table 3). The highest yielding cross produced 53.2 bushels as an average for the four years, while the original variety averaged 41.2 bushels. This cross exceeded the yield of the original variety each of the four years, although in one year the difference was well within the limits of experimental error. The eight crosses for which data are presented exceeded the original variety in bushels of shelled corn by an average of 17.2 %. In Nebraska, selfed strains with low leaf area yielded more than strains with high leaf area and crosses between strains with low leaf area were the most promising.

TABLE 3.—*Comparison of yields in bushels per acre of F_1 crosses between selfed strains with the original variety from which the selfed lines were obtained.* Nebraska Station. After Kiesselbach, 1922.

Cross or variety	Bushels per acre of shelled corn				Average
	1913	1915	1916	1917	
4 x 12	22.0	61.9	38.8	60.6	45.8
4 x 1	26.8	64.8	53.2	41.6	46.6
12 x 5	22.8	69.5	44.6	48.5	46.4
8 x 2	20.1	71.3	66.2	51.9	52.4
12 x 2	21.9	73.6	58.0	59.4	53.2
10 x 12	22.7	57.9	51.5	53.6	46.4
10 x 5	24.2	61.0	43.3	51.0	44.9
2 x 10	25.6	75.4	58.2	45.2	51.1
Average	23.3	66.9	51.7	59.3	48.3
Original	11.4	73.1	34.5	46.0	41.2

F_1 CROSSES IN IOWA

Results of corn yield contests conducted by the Iowa Corn and Small Grain Growers' Association have aided materially in proving the high-yielding ability of certain crosses (4). The data here summarized were taken from the report of the 1924 tests. H. A. Wallace, an enthusiastic supporter of the modern methods of corn breeding, has furnished data regarding these contests and other studies which he is conducting. The results of the contest in 1924 for the South Central Section, where several crosses were entered, are summarized in Table 4.

TABLE 4.—*Yields in bushels per acre of winners and source of seed in 1924.* Data from Iowa corn yield contests as summarized by Wallace.

Cross or variety	Place taken	Yield in bushels
Cross of inbred strains, U. S. D. A.	1st	51.3
Cross of inbred strains of Wallace	2nd	45.1
A cross of two strains of Leaming	3rd	41.2
Leaming 1–6 x Illinois Low Protein	4th	40.3
Chinese Bloody Butcher inbred strain x Illinois Low Protein	5th	40.2
Commercial Reid's Yellow, Highest yielder		39.1
Average yield of four crosses, inbred strains involved		44.2
Reid's Yellow Dent, 34 strains		34.5

The five highest yielding sorts were F_1 crosses and in four cases an inbred strain was used as one or both of the parents. The highest yield, 51.3 bushels per acre, was obtained from a cross entered by the United States Department of Agriculture, while the highest yielding commercial variety, a strain of Reid's Yellow Dent, produced 39.1 bushels per acre. The average yield of four crosses in which inbred strains were involved was 44.2 bushels, while the average yield of the 34 strains of Reid's Yellow Dent entered in the contest was 34.5 bushels. Mr. Wallace is conducting extensive tests at Ames in cooperation with H. D. Hughes and reports that many of these crosses have yielded much more than the standard variety with which they have been compared.

Hughes[4] made the following statement in a recent letter: "From the results secured thus far it is entirely evident that decidedly better yields can be secured from hybridizing pure lines than can be had from the best standard varieties of which we know. The data would also indicate that extensive ear-row breeding with subsequent crossing of the best lines even when carried through a long period of years can not be expected to give the results to be had from the production of pure lines and the use of F_1 seed."

RESULTS IN MINNESOTA

Crosses in which selfed strains were used have been grown at University Farm, St. Paul, Minnesota, for several years. Rather extensive field plat trials of double crosses were made in 1924 and 1925. During these two seasons the selfed lines used were isolated previously from standard high-yielding Minnesota varieties. Two such varieties recognized as standard for central Minnesota, Minn. No. 13 and Rustler White Dent, have been grown at University Farm for many years, the seed being selected in the field from perfect-stand hills and from vigorous healthy stalks. Close selection to score-card type of ear has not been practiced in recent years. Seed for three other varieties has been purchased yearly from Northrup King Seed Company and represents the better selections for these varieties.

The selfed strains used for the crosses were picked out on the basis of yield and the absence of striking abnormalities. Each F_1 cross was made by crossing two selfed strains within a variety which appeared unlike each other and the double crosses of these F_1 crosses were made at random. It is recognized that it would be more desirable to determine the strains which would combine to produce the better yielding crosses, and this method is being tried out. In the meantime, however, it appeared of interest to see what the results would be from combining on the basis of observable characters alone. The results for the two crop seasons are presented in Table 5.

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[4] Letter of Nov. 12, 1925, from Prof. Hughes to the writer.

In 1924, of a total of 21 double crosses tested, 3 yielded less than the higher yielding commercial variety One double cross exceeded the better commercial variety by 30%. The seven double crosses in which dent inbred strains were used yielded 13% more on the average than the better variety, while 12 flint-dent crosses averaged 9% more than the better variety. Of two flint double crosses one gave a low yield and the other yielded rather well. The results in 1925 were similar and certainly indicate that double crosses in which desirable appearing selfed lines are used may be expected to yield more than the present standard varieties.

TABLE 5.—*Percentage yield of double crosses obtained by crossing F_1 crosses between selfed lines where 100 is taken as the yield of the higher yielding standard variety.* University Farm, St. Paul, Minn., 1924–1925.

Crosses	Percentage yield classes									Number of crosses	Average percentage yield
	70	95	100	105	110	115	120	125	130		
1924											
Dent crosses			1	2	1	1		1	1	7	113.3
Flint Dent crosses		2		3	2	3	1	1		12	109.4
Flint crosses	1						1			2	95.5

Crosses	Percentage yield classes										Number of crosses	Average percentage yield
	85	90	95	100	105	110	115	120	125	130		
1925												
Dent crosses			1	2	1	1	1	2		1	9	110.1
Flint-Dent crosses				1	1		1				3	107.3
Flint crosses	1		1				2	1			5	105.5

The production of improved varieties through the recombination of several selfed strains has one advantage over either the single or double cross plan in that the farmer can save his own seed from the yearly crop and that yearly crosses need not be made. Little data regarding the value of this method are available.

At University Farm several recombinations of selfed strains within a variety were made in 1923 and the F_2 recombinations were compared with commercial varieties in 1925.

The methods used were as follows: Selfed strains were selected which appeared superior to the average and which were free from striking abnormalities. The recombination of selfed strains was obtained by pollinating several plants of each strain of a variety with a mixture of pollen from other strains of the same variety. An equal number of seeds from each such cross of each strain was bulked and planted the following year. Seed for later generations within each recombination was obtained by pollinating 50 plants with a mixture of pollen of 50 other plants. The comparisons of yielding ability of the standard varieties and of the F_2 recombinations are given in Table 6.

For the five comparisons there were three F_2 recombination families which yielded more than the standard variety and two which yielded less. The N. W. Dent F_2 recombination yielded 16.6% more than commercial N. W. Dent and appeared superior to N. W. Dent in the field.

TABLE 6.—*Yield of synthetic varieties compared with commercial varieties.*

University Farm, St. Paul, Minn., 1925.

Variety	Strains used for recombination Years selfed	Number	Yield, bushels per acre	Percentage increase or decrease
Minn. No. 13	–	–	51.3	
Minn. No. 13 F_2 recombination	1	5	45.3	—11.7
	3	3		
	8	1		
Rustler	–	–	44.8	
Rustler F_2 recombination	1	2	47.5	+ 6.0
	2	7		
	3	5		
	4	3		
N. W. Dent	–	–	51.9	
N. W. Dent F_2 recombination	1	2	60.5	+16.6
	3	8		
King Phillip	–	–	40.3	
King Phillip F_2 recombination	3	11	43.3	+ 7.4
Longfellow	–	–	43.9	
Longfellow F_2 recombination	3	8	40.1	— 8.7

While the data summarized have indicated the value of the present methods of corn breeding, it is apparent that many questions regarding methods have not yet been solved. The probable value of the present mode of attack justifies careful research studies. Some of the more pertinent questions which face the present-day corn breeder will now be discussed.

2. SOME QUESTIONS OF A RESEARCH NATURE WHICH REMAIN TO BE SOLVED

It is apparent that certain varieties when self-fertilized produce fewer striking abnormalities than others. Minn. No. 13, for example, contains numerous chlorophyll abnormalities, and in several hundred selfed lines 39.4% segregated the first season for seedling chlorophyll abnormalities, a much greater percentage than that found in other varieties (1). It has also appeared to be much more difficult to obtain desirable appearing selfed strains in quantity in Minn. No. 13 than in other varieties. In general, the better methods of work can be standardized, but more extensive studies may be necessary for some varieties than for others in order to produce sufficient desirable selfed lines.

A slogan of a previous meeting was "now that we have got them what are we going to do with them," referring to the fact that large numbers of selfed strains were available.

Perhaps, we may raise the question first of whether we have selfed strains which are as desirable as it is possible to get. Practically all selfed strains as yet available are inferior in vigor to normal commercial varieties. Should this fact be accepted as final evidence as to what is possible? If not, how much energy should be used in attempting to produce better selfed strains? Is it true that homozygosis and good yielding ability cannot be obtained in combination with each other?

With sunflowers, which are normally cross-pollinated and which formerly were thought to be self-sterile, McRostie (10) has observed lines that have been selfed for five years which are the equal of commercial varieties in vigor. Some lines of timothy which have been selfed for three or four years at University Farm are as tall, more leafy, and as desirable in other characters as commercial varieties and are also more uniform in type (2). Brewbaker at University Farm has been studying self-fertilization in rye. Some strains which he has obtained and which have been selfed three or four years appear relatively uniform and have yielded as well as commercial varieties.

Is there some physiological or genetic reason why similar results cannot be achieved eventually with corn. Extensive experiments must be made before a definite answer to this question can be given. What is the better mode of attack? Should large numbers of selfed lines be started from a variety or should fewer numbers be used with more careful selection within each original line? Perhaps the synthetic production of improved selfed lines may be achieved by crosses,

Table 7.—*Coefficients of correlation in selfed lines of corn which show the extent of inheritance of the character under the conditions of the experiment.*

Characters studied	Variety	Number of selfed lines	Years grown	Correlation coefficient
Yield, 1st with 2nd year selfed	Minn. No. 13 and Rustler	34	1921 and 1922	.321±.104
Yield, 2nd with 3rd year selfed	Minn. No. 13, Rustler, N. W. Dent	25	1921 and 1922	.182±.130
Yield, 2nd with 3rd year selfed	King Phillip	40	1921 and 1922	.386±.091
Yield, 1st with 2nd year selfed	Minn. No. 13 and Rustler	31	1922 and 1923	—.048±.121
Yield, 3rd with 4th year selfed	King Phillip	16	1922 and 1923	.307±.153
Yield, 1st with 2nd year selfed	Squaw	31	1923 and 1924	.203±.116
Yield, 1st with 2nd year selfed	Longfellow	26	1923 and 1924	.194±.127
Yield, 1st with 2nd year selfed	Minn. No. 13 and Rustler	32	1923 and 1924	—.086±.118
Yield, 2nd with 3rd year selfed	Minn. No. 13 and Rustler	30	1923 and 1924	.370±.106
Yield, 3rd with 5th year selfed	King Phillip	29	1922 and 1924	.237±.118
Length of ear, 1st with 2nd year selfed	Minn. No. 13 and Rustler	34	1921 and 1922	.419±.095
Length of ear, 2nd with 3rd year selfed	Minn. No. 13, Rustler, N. W. Dent	25	1921 and 1922	.449±.108
Length of ear, 2nd with 3rd year selfed	King Phillip	39	1921 and 1922	.429±.088
Length of ear, 1st with 2nd year selfed	Minn. No. 13 and Rustler	31	1922 and 1923	.336±.107
Length of ear, 3rd with 4th year selfed	King Phillip	16	1922 and 1923	.410±.140
Length of ear, 1st with 2nd year selfed	Squaw	31	1923 and 1924	.465±.095
Length of ear, 1st with 2nd year selfed	Longfellow	26	1923 and 1924	.496±.100
Length of ear, 1st with 2nd year selfed	Minn. No. 13 and Rustler	32	1923 and 1924	.124±.117
Length of ear, 2nd with 3rd year selfed	Minn. No. 13 and Rustler	30	1923 and 1924	.478±.095
Length of ear, 3rd with 5th year selfed	King Phillip	29	1922 and 1924	.370±.108
Number of ears, 1st with 2nd year selfed	Minn. No. 13 and Rustler	34	1921 and 1922	.296±.106
Number of ears, 2nd with 3rd year selfed	Minn. No. 13, Rustler, N. W. Dent	25	1921 and 1922	.056±.134
Number of ears, 2nd with 3rd year selfed	King Philip	40	1921 and 1922	.183±.103
Number of ears, 1st with 2nd year selfed	Minn. No. 13 and Rustler	31	1922 and 1923	.048±.121
Number of ears, 3rd with 4th year selfed	King Phillip	16	1922 and 1923	.219±.161
Number of ears, 1st with 2nd year selfed	Squaw	31	1923 and 1924	.134±.119
Number of ears, 1st with 2nd year selfed	Longfellow	26	1923 and 1924	.121±.130
Number of ears, 1st with 2nd year selfed	Minn. No. 13 and Rustler	32	1923 and 1924	.293±.109
Number of ears, 2nd with 3rd year selfed	Minn. No. 13 and Rustler	30	1923 and 1924	.007±.123
Number of 3rd with 5th year selfed	King Phillip	29	1922 and 1924	.440±.101
Size of seed with 2nd year selfed	Minn. No. 13 and Rustler	34	1921 and 1922	.124±.114
Size of seed with 3rd year selfed	Minn. No. 13, Rustler, N. W. Dent	25	1921 and 1922	.368±.117
Size of seed with 3rd year selfed	King Phillip	39	1921 and 1922	.130±.106

Size of seed, 1st with 2nd year selfed	Minn. No. 13 and Rustler	31	922 and 923	.390±.103
Size of seed, 3rd with 4th year selfed	King Phillip	16	922 and 923	573±.113
Size of seed, 1st with 2nd year selfed	Squaw	31	923 and 924	.225±.115
Size of seed, 1st with 2nd year selfed	Longfellow	26	923 and 924	.424±.108
Size of seed, 1st with 2nd year selfed	Minn. No. 13 and Rustler	32	923 and 924	.509±.088
Size of seed, 2nd with 3rd year selfed	Minn. No. 13 and Rustler	30	923 and 924	.707±.062
Size of seed, 3rd with 5th year selfed	King Phillip	29	922 and 924	.258±.117
Lodging index, 1st with 2nd year selfed	Minn. No. 13 and Rustler	34	921 and 922	.103±.114
Lodging index, 2nd with 3rd year selfed	Minn. No. 13, Rustler, N. W. Dent	25	921 and 922	—.212±.129
Lodging index, 2nd with 3rd year selfed	King Phillip	40	921 and 922	180±.103
Lodging index, 1st with 2nd year selfed	Minn. No. 13 and Rustler	31	922 and 923	.191±.117
Lodging index, 3rd with 4th year selfed	King Phillip	13	922 and 923	.517±.137
Lodging index, 1st with 2nd year selfed	Squaw	31	923 and 924	.464±.095
Lodging index, 1st with 2nd year selfed	Longfellow	26	923 and 924	.188±.128
Lodging index, 1st with 2nd year selfed	Minn. No 13 and Rustler	32	923 and 924	.461±.094
Lodging index, 2nd with 3rd year selfed	Minn. No. 13 and Rustler	30	923 and 924	.325±.110
Lodging index, 3rd with 5th year selfed	King Phillip	25	922 and 924	.448±.108
Percentage of smut infection, 1st with 2nd year selfed	Minn. No. 13 and Rustler	34	921 and 922	.676±.063
Percentage of smut infection, 2nd with 3rd year selfed	Minn No. 13, Rustler, N. W. Dent	25	921 and 922	.119±.133
Percentage of smut infection, 2nd with 3rd year selfed	King Phillip	39	921 and 922	.105±.099
Percentage of smut infection, 1st with 2nd year selfed	Minn. No. 13 and Rustler	31	922 and 923	.189±.117
Percentage of smut infection, 3rd with 4th year selfed	King Phillip	16	922 and 923	.284±.155
Percentage of smut infection, 1st with 2nd year selfed	Squaw	31	923 and 924	.568±.082
Percentage of smut infection, 1st with 2nd year selfed	Longfellow	26	923 and 924	.690±.069
Percentage of smut infection, 1st with 2nd year selfed	Minn. No. 13 and Rustler	32	923 and 924	.287±.109
Percentage of smut infection, 2nd with 3rd year selfed	Minn. No. 13 and Rustler	30	923 and 924	.524±.089
Percentage of smut infection, 3rd with 5th year selfed	King Phillip	29	922 and 924	.082±.124
Cob discoloration, 1st with 2nd year selfed	Minn. No. 13 and Rustler	34	921 and 922	.356±.101
Cob discoloration, 2nd with 3rd year selfed	Minn. No. 13, Rustler, N. W. Dent	25	921 and 922	.451±.107
Cob discoloration, 2nd with 3rd year selfed	King Phillip	39	921 and 922	.058±.108
Cob discoloration, 1st with 2nd year selfed	Minn. No. 13 and Rustler	31	922 and 923	.209±.116
Cob discoloration, 3rd with 4th year selfed	King Phillip	16	922 and 923	.672±.093
Cob discoloration, 1st with 2nd year selfed	Squaw	30	923 and 924	.562±.084
Cob discoloration, 1st with 2nd year selfed	Longfellow	26	923 and 924	.659±.075
Cob discoloration, 1st with 2nd year selfed	Minn. No. 13 and Rustler	32	923 and 924	.226±.113
Cob discoloration, 2nd with 3rd year selfed	Minn. No. 13 and Rustler	30	923 and 924	.427±.101
Cob discoloration, 3rd with 5th year selfed	King Phillip	29	922 and 924	.405±.105

TABLE 8.—*Correlation between yield and various characters of selfed lines of corn.*

Yield index correlated with	Variety	Number of years selfed	Number of strains	Year	Correlation coefficient
Length of ear index	Pl. Path. Minn. Mo. 13, Rustler, N. W. Dent, King Phillip and Longfellow	2	45	1921	.320±.090
Length of ear index	Pl. Br. 1 and 2 year selfed strains of Minn. 13 and Rustler	1 & 2	50	1921	.684±.051
Length of ear index	Pl. Br. King Phillip	3	40	1922	.622±.065
Length of ear index	Pl. Br. Minn. No. 13 and Rustler	2	34	1922	.796±.042
Length of ear index	Pl. Br. Minn. No. 13, Rustler, and N. W. Dent	3	25	1922	.248±.127
Length of ear index	Pl. Br. Minn. No. 13 and Rustler	2	31	1923	.921±.018
Length of ear index	Pl. Br. King Phillip	4	16	1923	.502±.126
Length of ear index	Pl. Br. Squaw	2	31	1924	.814±.041
Length of ear index	Pl. Br. Longfellow	2	26	1924	.594±.086
Length of ear index	Pl. Br. Minn. No. 13 and Rustler	2	32	1924	.706±.060
Length of ear index	Pl. Br. Minn. No. 13 and Rustler	3	20	1924	.768±.051
Length of ear index	Pl. Br. King Phillip	5	29	1924	.727±.059
Number of ears index	Pl. Br. King Phillip	3	40	1922	.636±.064
Number of ears index	Pl. Br. Minn. No. 13 and Rustler	2	34	1922	.818±.038
Number of ears index	Pl. Br. Minn. No. 13, Rustler and N. W. Dent	3	25	1922	.539±.096
Number of ears index	Pl. Br. Minn. No. 13 and Rustler	2	31	1923	.682±.065
Number of ears index	Pl. Br. King Phillip	4	16	1923	.693±.088
Number of ears index	Pl. Br. Squaw	2	31	1924	.896±.024
Number of ears index	Pl. Br. Longfellow	2	26	1924	.843±.038
Number of ears index	Pl. Br. Minn. No. 13 and Rustler	2	32	1924	.829±.037
Number of ears index	Pl. Br. Minn. No. 13 and Rustler	3	30	1924	.719±.059
Number of ears index	Pl. Br. King Phillip	5	29	1924	.681±.067
Size of seed	Pl. Path. Minn. No. 13, Rustler, N. W. Dent, King Phillip and Longfellow	2	47	1921	.073±.098
Size of seed	Pl. Br. All strains	1 & 2	104	1921	.183±.064

Size of seed	Pl. Br. King Phillip	3	40	1922	.315±.096
Size of seed	Pl. Br. Minn. No. 13 and Rustler	2	34	1922	.014±.116
Size of seed	Pl. Br. Minn. No. 13, Rustler and N. W. Dent	3	25	1922	.341±.119
Size of seed	Pl. Br. Minn. No. 13 and Rustler	2	31	1923	.011±.121
Size of seed	Pl. Br. King Phillip	4	16	1923	.241±.152
Size of seed	Pl. Br. Squaw	2	31	1924	.026±.121
Size of seed	Pl. Br. Longfellow	2	26	1924	−.299±.120
Size of seed	Pl. Br. Minn. No. 13 and Rustler	2	32	1924	−.129±.117
Size of seed	Pl. Br. Minn. No. 13 and Rustler	3	30	1924	.365±.017
Size of seed	Pl. Br. King Phillip	5	29	1924	.407±.104
Lodging index	Pl. Path. Minn. No. 13, Rustler, N. W. Dent. King Phillip and Longfellow	2	45	1921	.020±.098
Lodging index	Pl. Br. All strains	1 & 2	104	1921	.061±.066
Lodging index	Pl. Br. King Phillip	3	40	1922	.034±.107
Lodging index	Pl. Br. Minn. No. 13 and Rustler	2	34	1922	−.147±.113
Lodging index	Pl. Br. Minn. No. 13 and Rustler, N. W. Dent	3	25	1922	−.043±.135
Lodging index	Pl. Br. Minn. No. 13 and Rustler	2	31	1923	−.125±.119
Lodging index	Pl. Br. King Phillip	4	16	1923	.289±.155
Lodging index	Pl. Br. Squaw	2	31	1924	508±.090
Lodging index	Pl. Br. Longfellow	2	26	1924	.173±.128
Lodging index	Pl. Br. Minn. No. 13 and Rustler	2	32	1924	.328±.106
Lodging index	Pl. Br. Minn. No. 13 and Rustler	3	30	1924	.349±.108
Lodging index	Pl. Br. King Phillip	5	29	1924	−.131±.123
Smut infection percentage	Pl. Path. Minn. No. 13, Rustler, N. W. Dent, King Phillip and Longfellow	2	48	1921	.039±.097
Smut infection percentage	Pl. Br. All strains	1 & 2	104	1921	−.023±.066
Smut infection percentage	Pl. Br. Minn. No. 13 and Rustler	2	34	1922	−.394±.098
Smut infection percentage	Pl. Br. Minn. No. 13, Rustler and N. W. Dent	3	25	1922	−.040±.135
Smut infection percentage	Pl. Br. King Phillip	3	40	1922	−.047±.106

TABLE 8.—*Continued.*

Yield index correlated with	Variety	Number of years selfed	Number of strains	Year	Correlation coefficient
Smut infection percentage	Pl. Br. Minn. No. 13 and Rustler	2	31	1923	-.104±.120
Smut infection percentage	Pl. Br. King Phillip	4	16	1923	-.026±.169
Smut infection percentage	Pl. Br. Squaw	2	31	1924	-.387±.103
Smut infection percentage	Pl. Br. Longfellow	2	26	1924	-.147±.129
Smut infection percentage	Pl. Br. Minn. No. 13 and Rustler	2	32	1924	.022±.119
Smut infection percentage	Pl. Br. Minn. No. 13 and Rustler	3	30	1924	-.187±.119
Smut infection percentage	Pl. Br. King Phillip	5	29	1924	.255±.117
Cob discoloration index	Pl Path. No. 13, Rustler, N. W. Dent, King Phillip and Longfellow	2	45	1921	.085±.100
Cob discoloration index	Pl. Br. All strains	1 & 2	104	1921	-.030±.066
Cob discoloration index	Pl. Br. Minn. No. 13 and Rustler	2	34	1922	-.077±.115
Cob discoloration index	Pl. Br. Minn. No. 13, Rustler and N. W. Dent	3	25	1922	-.008±.135
Cob discoloration index	Pl. Br. King Phillip	3	40	1922	.021±.107
Cob discoloration index	Pl. Br. Minn. No. 13 and Rustler	2	31	1923	.081±.120
Cob discoloration index	Pl. Br. King Phillip	4	16	1923	-.472±.131
Cob discoloration index	Pl. Br. Squaw	2	30	1924	-.459±.097
Cob discoloration index	Pl. Br. Longfellow	2	26	1924	-.001±.132
Cob discoloration index	Pl. Br. Minn. No. 13 and Rustler	2	32	1924	-.202±.114
Cob discoloration index	Pl. Br. Minn. No. 13 and Rustler	3	30	1924	-.347±.108
Cob discoloration index	Pl. Br. King Phillip	5	29	1924	-.153±.122
Seedling vigor	Pl. Br. Squaw	2	29	1924	-.150±.122
Seedling vigor	Pl. Br. Longfellow	2	26	1924	-.203±.127
Seedling vigor	Pl. Br. Minn. No 13 and Rustler	2	32	1924	.155±.116
Seedling vigor	Pl. Br. Minn. No. 13 and Rustler	3	29	1924	.472±.069
Seedling vigor	Pl. Br. King Phillip	5	23	1924	.568±.095

followed by subsequent selection, of two or more selfed lines which contain in each case important genetic factors which the others lack.

What characters then should be sought for in selfed lines? It is very evident that disease resistance is an important character and in the light of information now available it appears that resistance to each particular parasite is specific and dependent upon genetic factors which are inherited in the same general manner as other genetic factors. Obtaining strains, therefore, which are resistant to all important diseases is a problem in itself; and the necessity likewise of combining in the same strain other favorable growth factors makes the problem still more difficult. The probable productive capacity in themselves of selfed lines canot be estimated with accuracy, but better lines can be obtained without doubt than are now available. The importance of obtaining the best lines possible warrants extensive studies. During the period of these studies there are, as has been emphasized, sufficient data available to prove that the cost of the studies can in the near future be repaid many times through the commercial uses of improved sorts.

The characters in selfed lines which, in general, are correlated with vigor should be learned. In recent years, at University Farm, individual characters of selfed lines have been determined with the hope of learning the relative importance of such characters. The yield for each selfed line has been obtained from harvesting 20 single-stalk hills which are grown a distance of 1 foot apart in the row. Data on ear length, number of ears index computed on the basis of quality and number of ears without regard to length, size of seed, and cob discoloration index have been obtained by a study of the ears produced by these 20 stalks. Lodging index and percentage of smut infection have been obtained from a study in the field of approximately 35 single-stalk hills, all of which are grown in the same plat, while seedling vigor has been estimated by the vigor of growth of seedlings produced by 20 kernels when planted in sand in the greenhouse.

To determine the extent of inheritance of the characters in question correlation coefficients for the relative expression of the character in different selfed generations have been computed (Table 7).

In general, the larger coefficients were obtained for length of ear, size of seed, and cob discoloration, also, for some varieties, percentage of smut infection and lodging were rather strongly correlated in the different selfed generations. Yielding ability of separate selfed generations gave a positive correlation in most cases.

Because of the importance of yielding ability the relation of yield and other characters of selfed strains is of interest. In these studies, as in the studies of inheritance of particular characters of selfed lines, the strain is the unit and correlations expressing the relationship of yield and of other characters have been computed (Table 8).

Yield of selfed strains is strongly correlated with other characters which are expressions of vigor, such as length of ear, number of ears index, and, to a less degree on the average, with size of seed, although as size of seed is rather strongly correlated in different generations of selfing the relationship shown becomes of some importance.

Kyle and Stoneberg (9) found that selfed lines with fewer number of rows per ear produced relatively longer ears, were freer from abnormalities, and more resistant to smut, on the average, than lines which produced more rows of kernels to the ear.

In the studies carried out at University farm, percentage of smut infection was not markedly related to yielding ability, although a tendency to a negative correlation is noted. Similar results were obtained for cob discoloration. In some varieties seedling vigor was strongly correlated with yielding ability and in other cases there appeared to be no relation between seedling vigor and yield. In general, the results here presented corroborate those of Jones and Mangelsdorf (7) and show that the only sure criterion of the value of any particular selfed line is the progeny test. This is in line with previous studies with other crops. Selection must be practiced eventually. however, and selection in the segregating generations, while not always particularly effective, appears nevertheless to be well worth while in so far as the characters concerned are the result of genotypic differences.

The question of how long to continue selfing and selection before recombining selfed strains is of importance. Complete homozygosis, providing sufficient vigor can be retained, is the ideal condition. Perhaps, however, from the practical standpoint it may be necessary only to self until the strain appears relatively uniform and free from striking abnormalities.

Richey and co-workers (11, 12) have found that F_1 crosses between strains which were selected after self-fertilization had been continued for three generations were, on the average, as productive as similar F_1 crosses made after six generations of selfing. Results of this nature indicate that it may not be necssary to attain homozygosis before recombining selfed strains. After a selfed strain has become relatively uniform it can be kept in the same state by some system of off-pollination within the strain. If selfing is continued until complete homozygosis is obtained further reduction in vigor will be brought about, as a rule, without necessarily leading to higher yielding ability in F_1 crosses. Further studies along this line are necessary.

It seems reasonable to conclude that crosses between higher yielding strains should, as a general rule, be of greater value than crosses between low-yielding strains, although in the light of our present genetic knowledge many cases of individual exception should be expected. For example, a cross between a low-yielding golden strain which, except for the factor for golden may contain many favorable growth factors, with a low-yielding normal strain, which contains some favorable growth factors not found in the golden strain, might give high yields in F_1. Kiesselbach (8) found that, in general, F_1 crosses between high-yielding strains were superior in yielding ability to F_1 crosses between low-yielding strains, while the data of Richey and Mayer (12) indicate no such general relation. Further extensive experiments are needed.

After obtaining desirable selfed strains, how shall they be used? The more important methods appear to consist of the use of hybrid vigor which is obtained from either single or double crosses, or the synthetic production of improved varieties. Maximum yields may be expected from recombining selfed lines. If resistance to some particular disease is of major importance and resistant lines can be obtained, there is every reason to expect that improved synthetic varieties can be secured. The extent to which F_1 crosses will exceed synthetic varieties in yielding ability apparently will depend on the extent to which good vigor and homozygosis can be associated in selfed lines Whether F_1 crosses will be commonly grown commercially as the main corn crop remains for the future to decide. It must be emphasized that the method of using F_1 single or double crosses as the commercial crop appears to be a scientifically logical procedure and sufficient experimental evidence is available already to demonstrate its probable value.

It is apparent that the only sure means of learning how selfed strains will perform in particular crosses is by the experimental tests. In the next few years, therefore, extensive trials must be made of all possible combinations of desirable selfed strains. If sufficiently vigorous selfed strains can be obtained, the method of using F_1 crosses as the commercial crop may perhaps be the most desirable. Double crosses of F_1 crosses may prove a still more favorable method and in certain cases synthetic varieties may prove of value. If it proves necessary to use F_1 crosses, there is the possibility that F_1 crosses of synthetic varieties may in some cases give maximum yields. Before combining strains as a commercial practice all possible F_1 combinations of the available selfed strains, which in themselves appear of promise, should be tried out

In these studies the importance of proper field plat technic is very great. The development of sound methods of comparison for the comparative trial of extensive crosses, improved varieties, and selfed lines is a necessary part of a corn improvement program. The problems which need to be solved are similar to those faced in most field experiments. They are concerned largely with a determination of the most feasible size of plat, the number of replications, the question of competition, and the use of the probable error concept in an analysis of the results.

SUMMARY

1. The modern method of corn breeding has resulted from the development of a sensible genetic interpretation of the results of selfing and crossing in naturally cross-pollinated species and in these studies the work with corn has played an important rôle. Perhaps, of equal importance is the fact that adapted varieties cannot, as a rule, be further improved by the use of earlier methods.

2. To the agronomist or other investigator not primarily trained in genetics the best evidence of the value of modern methods is the experimental proof that real progress in obtaining improved sorts has been made. The evidence of experiments now available has been reviewed. The results of these experiments justify the belief that higher yielding sorts or improved quality of product or both can be secured by present-day methods of breeding. In many cases yields have been increased as much as 30%. Such diseases as smut and the ear, root, and stalk rots can be controlled apparently.

3. In order to accomplish the desired results extensive studies must be made and it must be appreciated that breeding cross-pollinated plants by some system of controlled pollination cannot be carried out without considerable effort

4. The importance of obtaining the best possible selfed lines warrants extensive studies. Desirable selfed lines must contain necessary genetic factors for resistance to specific diseases combined with as many favorable growth factors as possible. Whether large numbers of original selfed lines should be used or smaller numbers with more extensive selection within each line is not yet known. Perhaps better selfed lines can be obtained by selection from crosses between selfed lines which contain necessary complementary growth factors or factors for resistance to diseases. In certain cross-pollinated crops self-fertilized lines which in themselves appear as vigorous or more

vigorous than normal varieties have been obtained. Extensive study is needed to determine the possibilities with corn.

5. After obtaining what appear to be desirable selfed lines the study of performance of these lines in F_1 crosses is a logical step. The only sure method of learning which strains combine to produce the greatest vigor in F_1 is by testing all possible F_1 combinations. After this the relative value of single crosses, double crosses, and synthetic varieties can be determined.

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BOOK REVIEWS

GENETICS IN PLANT AND ANIMAL IMPROVEMENT

By Donald Forsha Jones. The Wiley Agricultural Series, edited by J. G. Lipman. John Wiley and Sons, New York. Pp. 568, Figs. 229. 1925.

This book is designed to fill the need for a textbook of genetics written from the agricultural point of view. The rapid increase in the number of agricultural colleges requiring an elementary course in genetics makes such a book a welcome contribution. Since the author is not only one of the leading practical plant breeders but has made important contributions to genetic theory as well, he is qualified to speak with authority in this field.

The most striking feature of the book is the novel organization of the subject matter. Abandoning the familiar order of presentation commonly followed in genetic textbooks, it presents the subject in a new arrangement with greatly increased emphasis on the phases important in economic breeding. Thus "Inbreeding" and "Sterility" are each given a long chapter, together occupying 104 pages, while the whole subject of Mendelian inheritance, including dominance, factorial inter-relationships, quantitative inheritance, multiple allelomorphism, linkage, and the chromosome theory, is treated adequately though not elaborately in two chapters which together cover 63 pages. Some readers may feel that this shift of emphasis has been carried too far, but it would be difficult to point out specifically a phase of the subject which is not treated as fully and clearly as would be desirable in an elementary text.

The general arrangement and scope of the work are indicated by the chapter headings: The Relations of Animals and Plants to Their Surroundings, How Living Organisms Reproduce Themselves, Segregation and Recombination, The Carriers of the Inheritance, Sex and Sex-Linked Characters, Variations Large and Small, Measuring Variation and Correlation, Composition of Plant and Animal Populations, Hybridization in Plant and Animal Improvement, Vigor Accompanying Hybridization, Inbreeding, Sterility, Methods for Plant Improvement, Methods for Animal Improvement. The final chapters on plant and animal improvement, it is explained in the preface, are designed to be supplemented by special texts on these subjects, when the course in genetics is followed by courses in applied plant and animal breeding.

The book will naturally be compared to Babcock and Clausen's *Genetics in Relation to Agriculture*, since this also was prepared primarily for use in agricultural colleges. This valuable work, sound, exhaustive, and scholarly, has been found almost as baffling to the American sophomore as a German *Handbuch*, which in fact it somewhat resembles. As a reference and guide to the advanced student it is in a class by itself, far superior to any other general treatise on genetics, American or foreign. But as an elementary text it suffers from an embarassment of riches; it is too complete and detailed; the average elementary student is unable to follow it. Jones has avoided this difficulty. He presents clearly and simply the essential features covered in an elementary course, illustrating them by discriminating choice of experimental evidence. No attempt is made to cite all of the important work, evidence being given only as required for a clear understanding of the subject. The illustrations are numerous and well-chosen, the explanatory graphs and diagrams being especially noteworthy.

But there is no sacrifice of soundness to simplicity. We have had an abundance of simple textbooks of genetics and of plant and animal breeding, but usually these have achieved simplicity by omitting all but the simplest phases of the subject, and more than one of them have been actually unsound. Jones' book is sound and comprehensive. It will serve a very useful purpose as a textbook for elementary courses in genetics in agricultural colleges, for it is by all odds the best text now available for such courses.

(L. J. Stadler.)

THE SCIENCE OF SOILS AND MANURES

By J. Alan Murray. D. Van Nostrand Company, New York, Third Edition. Pages XIV + 298. Figs. 45. 1925.

It is refreshing for an American interested particularly in the subject of soils and fertilizers to read this book of Murray's. The viewpoint is European. It is markedly influenced by what might be termed a mature agriculture. In America, agriculture is so new and so immature, comparatively speaking, that American books on soils are either couched in terms of generalities or in terms of uncertainty. Again, American books are apt to be popular and partake of applied science rather than of pure science. English books are not so. They are written with greater exactness, and pure science is drawn upon freely in the discussions.

This book is a revision of that published under the same name in 1910, although the revision has been so thorough that a great deal of it has been rewritten. The book has beeen prepared primarily for students of soils and fertilizers, but also to meet a certain demand among farmers and gardeners.

The first chapter on the origin of soils deals largely with rock and mineral weathering and the geological classification of soils. No attempt is made to include the more modern ideas of soil development, or to discuss the characteristics of the soil profile.

The chapter on the physical properties of soils covers approximately 50 pages and as a summary of our present knowledge is especially well written. It includes brief mathematical interpretations and has the tone of a treatise on pure science. The chapters on soil chemistry and soil biology, while very brief summaries of modern concepts, are well done. The sciences of chemistry and biology are drawn upon freely in the interpretations, yet the style is simple and very readable.

The latter half of the book is given over to the discussion of the principles of manuring and fertilizing; including a considerable amount of material on fertilizer manufacture. It is largely this part of the book which is intended for the use of practical men. While the viewpoint is English and the method of approach is more that of the pure scientist than of the specialist in soil management, the material should be very useful to the English cultivator. It is, however, not the type of material which the American farmer finds in the bulletins of his experiment station.

The author does not seem to be familiar with the progress that has been made in the United States in the manufacture of legume inoculants. He mentions the early European attempts in the preparation of the so-called "Nitragin" and dismisses the discussion with the statement that the sale of this material was discontinued, although the attempt was not without historical interest.

Another omission of interesting work that is being done in this country has to do with the influence of gypsum on the structural condition of certain alkali soils. The author discusses the effect of gypsum in correcting black alkali, but states that it has no influence on white alkali soils. The discussion of artificial nitrogen fixation is also rather incomplete, the Haber process and certain other modern developments not being mentioned. The discussion is limited entirely to the manufacture of nitrate of lime and calcium cyanamide.

On the whole, the book is not only exceedingly well written, but it contains a large amount of most valuable material. It is an excellent resumé of our knowledge of the science of soils and fertilizers The appendix includes much tabular material of value to the student American students of soils and fertilizers will find this book a very worthy one for their libraries (M. F. MILLER.)

NOTES

CONCERNING THE GROWTH OF MUNG BEANS ON SUBMERGED LAND

At the Biggs Rice Field Station, located at Biggs, California, in November, 1923, a crop of partially mature mung beans was plowed under for green manure The following April, the land was replowed, double disked, and dragged. These cultural operations prepared a good seedbed. On April 29, rice was sown on this land and it was irrigated the following day On May 9 and 18, the land was irrigated and drained the second and third times, respectively. These irrigations, in addition to germinating and maintaining the growth of the rice, also germinated quite a large number of mung bean seeds. The bean seedlings grew quite rapidly during the period of alternate flooding and draining from April 30 to May 27. On May 27, the rice was again irrigated, after this date some water being held on the land and the depth gradually increased until it was submerged about 6 inches by June 12. The water thereafter was held at about this depth until the land was drained on September 18 preceding the rice harvest.

A large number of the mung bean plants that had emerged during the period of alternate flooding and draining died when the land was continuously submerged. A number of the bean seedlings, however, continued to grow slowly after the land was submerged. When the land was drained for harvest on September 18, these mung bean plants were comparatively short, ranging in height from 16 to 24 inches. The main stalks were delicate and averaged only about 1/16 inch in diameter. The leaves also were small, varying in width at the widest point from 1½ to 1¾ inches.

Numerous fine roots, most of which were adventitious, were present on the stems having arisen from the nodes submerged in the water. These fine roots, very few of which penetrated the soil but remained partially embedded on its surface, were observed to be well supplied with nodules.

It is of interest to know: (1) That mung bean plants grew slowly for over three months on land continuously submerged with water to a depth of about 6 inches; and (2) that numerous nodules developed on the fine adventitious roots arising from the submerged stem nodes. This indicates that the nodule organism (*Bacillus radicocola*) of the mung bean probably is less sensitive to an excess of water than are the mung bean plants themselves, for many of the latter died and those that remained alive made but poor growth in the water. The fact that numerous nodules developed on the mung bean roots in the water indicates that nitrates were not present in the water in sufficient quantities to inhibit nodule formation. The nitrogen of the atmosphere was not available to the submerged bacteria and it is, therefore, likely that the relationship of the nodule organism to the mung bean plants under water was not symbiotic, being probably entirely parasitic under such conditions.— JENKIN W. JONES, *Associate Agronomist, office of Cereal Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, and Superintendent of Biggs Rice Field Station, Biggs, Calif.*

THE MILLING AND BAKING QUALITIES OF WHEAT 25 YEARS OLD

A small sample of wheat known to be 25 years old was received by the Kansas State Agricultural College on August 7, 1925, from G. W. Schmidt of Junction City, Kansas. Mr. Schmidt had placed the wheat in a tin pail with a tight fitting cover and hung it in a granary. He recalled that the pail had been hung there when his boys were small and now they are men over 30 years old. Fortunately, there had been no damage from weevil. A germination test was made in the seed laboratory, but not a single kernel gave evidence of life. The wheat was dark red and the kernels plump. While there was no evidence of weevil, there was a considerable amount of bran powder. This had probably been produced by the contraction and expansion of the kernels due to changes in moisture content and temperature.

The test weight of the wheat as received was 55.8, and after passing through the wheat separator it was 56.3. As the wheat was free from chaff and other impurities the increase in test weight was due to the removal of the bran powder.

The wheat was milled in an experimental mill and produced 70% total flour. Five per cent of water was required to temper the wheat and the loss in scouring was 1%. These figures are very nearly the same as those obtained for a normal sample of wheat. The normal scouring loss indicated that the brittleness of the bran coat had not been materially increased. The expansion and contraction which had produced the bran powder had evidently only affected the outermost layer in the bran coat. The miller who made the milling test observed that, "This sample has a very peculiar odor, old, and does not appear to have normal life in it." The amount of tempering water was the same as used on normal Kansas hard winter wheat.

The chemical analysis gave the following results:

	%
Moisture in the wheat	10.72
Moisture in the flour	11.63
Protein in the wheat	12.40
Protein in the flour	11.20
Ash in the flour	0.61

The amount of moisture in the wheat was approximately the same as obtained in samples from the crop of 1925. The percentage of moisture in the flour was lower than normal, indicating that the water added in the tempering process was not as strongly adsorbed as in ordinary wheat and hence evaporated during the milling process. This possibly accounts for the high ash.

The baking test on the flour from this old wheat gave the following results in comparison with flour milled from wheat harvested in 1925:

Oven rise, cm.	0.0	8.8
Loaf volume, cc.	1,140	2,090
Color, %	75	98
Texture, %	75	98

The behavior of this flour in baking and the properties of the baked loaf and of the gluten washed from the flour were very similar to those observed when wheat has been injured by heating in the stack or bin or when germination has proceeded too far. Apparently the injury to the baking qualities wrought by the long process of aging is very similar to that which takes place very rapidly under those conditions which cause germination or heat damage.—C. O. SWANSON, *Kansas State Agricultural College, Manhattan, Kan.*

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DO LEGUME LEAVES HASTEN THE CURING PROCESS BY PUMPING MOISTURE FROM THE STEMS?[1]

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A very prevalent theory of haymaking is that legume leaves must be kept green as long as possible in order that they may dry the stems by pumping water from them. A recent textbook (2)[3] says, "Legume hay crops cure best under conditions which prevent the drying of the leaves Transpiration is thus allowed to continue and the moisture in the stems is largely drawn out through the leaf surface In the windrow or swath the majority of leaf surfaces are protected from the sun and continue to exude moisture by transpiration." Others (1 and 4) have recently made the same explanation. In fact one of the leading manufacturers of hay tools is advertising a special system of curing hay which is supposed to be based on this drying of the stems by the leaves. Just where the theory originated the writer has not discovered. The earliest statement of it he has seen is in "Clover Culture" by Henry Wallace (5). From these and many other sources the theory has become well known throughout the corn belt The writer has seen no contradiction of it until this year, when Piper, et al (3) express doubt of its correctness.

From the standpoint of plant physiology it has always been a little difficult to understand exactly how the leaves could remove very much water from the stems. In many, if not most, plants the stomata close as soon as the leaf wilts even slightly, and the leaf no longer favors rapid evaporation, but resists water loss for days.

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[1] Contribution from the Department of Farm Crops, Ohio State University, Columbus, Ohio. Received for publication January 12, 1926.

[2] Assistant Professor.

[3] Reference by number is to "Literature Cited," p. 375.

An extreme example is tobacco, leaves of which require weeks to become air dry in the shade at room temperature. Under any circumstance it is difficult to see how more water could be removed than is actually in the water conducting vessels, since most of the water in the stems must be in the living cells and it does not seem likely that these would give up water to a transpiration current. It would be difficult to determine just what proportion of the total amount of moisture in the stem is actually in the water conducting tubes, but it must be rather small.

This paper is a partial report of experiments concerned with the effect of physiological factors on the curing of hay, and gives preliminary data on the effect of the leaves in curing the stems. Duplicate samples made up of one to five stems of the plant being worked with were selected, one being allowed to dry normally, the other having the leaves and in some instances the very small side branches clipped off. The normal and clipped samples were always placed side by side on a table freely exposed to the air in a laboratory which had an approximately constant temperature of 80°F. and was subject to but few drafts. The leaves of the clipped samples were spread out in approximately the same position along the stem as that which they occupied before being clipped. Weights of both stems and leaves were taken at frequent intervals for the first day and at least once a day until the samples were entirely air-dry, but for the purposes of this paper it does not seem necessary to give the mass of data thus accumulated. The problem here is only with the relative moisture content of the normal and clipped stems. In order to determine whether the leaves had actually hastened the drying of the normal stems, the leaves were clipped from them at the close of the experiment and the stems weighed separately. The air-dry or moisture-free weights of the stems were then obtained, and the percentage of moisture present in the stems at the end of the drying period calculated. This made possible a comparison of the moisture content of the stems of the normal and clipped samples subjected to otherwise uniform conditions.

The results of tests of this kind are given in Table 1.

It is evident from Table 1 that different plants behaved differently in regard to the effect of the leaves on water loss from the stems. In no instance was there any significant difference between the moisture content of the stems of clipped and normal samples of alfalfa. Several in fact seemed to show that the stems with the leaves removed dried faster than the normal stems, but this is probably due to various experimental errors. If more careful and extensive work should

TABLE I.—*Influence of leaves on the drying of forage stems.*

Test begun	Crop	Period of drying, hours	Percentage moisture in stems	
			Leaves left on	Leaves clipped off
September 13, 1923	Sweet clover	3.9	61	57
September 13, 1923	Sweet clover	16.5	42	38
September 13, 1923	Sweet clover	27.5	34	27
September 13, 1923	Alfalfa	4.0	81	74
September 13, 1923	Alfalfa	17.0	65	55
Setpember 13, 1923	Alfalfa	27.8	48	44
September 13, 1923	Red clover	13.5	71	71
September 13, 1293	Red clover	25.0	55	59
September 13, 1923	Soybeans	4.3	72	74
September 13, 1923	Soybeans	17.8	61	67
May 24, 1924	Sweet clover	50.4	73.7	81.0
September 16, 1924	Sweet clover	19.3	43.7	50.3
September 16, 1924	Sweet clover	45.5	32.6	27.6
September 13, 1924	Alfalfa	3.7	67.5	67.5
September 13, 1924	Alfalfa	57.2	24.1	26.2
September 13, 1924	Alfalfa	3.6	64.6	67.6
September 13, 1924	Alfalfa	56.5	16.3	14.3
September 13, 1924	Alfalfa	3.3	68.9	72.6
September 13, 1924	Alfalfa	51.3	34.9	40.5
September 13, 1924	Alfalfa	22.0	51.3	48.6
September 16, 1924	Alfalfa	47.8	30.8	34.3
September 16, 1924	Alfalfa	46.7	36.7	25.5
September 16, 1924	Alfalfa	53.3	36.8	37.4
Average, 1924	Alfalfa		43.2	43.5
September 13, 1924	Peking soybeans	13.9	58	65
September 13, 1924	Peking soybeans	39.2	45	48
September 13, 1924	Peking soybeans	13.9	58	66
September 13, 1924	Peking soybeans	38.9	45	50
September 13, 1924	Peking soybeans	18.7	53	65
September 14, 1924	Peking soybeans	35.3	44	54
September 14, 1924	Peking soybeans	28.6	47	53
September 19, 1924	Peking soybeans	23.4	53	59
Average, 1924	Peking soybeans		50.4	57.5
September 13, 1924	Manchu soybeans	16.2	65.7	67.9
September 13, 1924	Manchu soybeans	26.1	63.7	66.0
September 13, 1924	Manchu soybeans	13.9	65.4	68.3
September 13, 1924	Manchu soybeans	23.6	64.4	66.4
September 16, 1924	Manchu soybeans	18.5	67.6	71.7
September 16, 1924	Manchu soybeans	19.2	68.4	70.6
Average, 1924	Manchu soybeans		65.9	68.5
June 11, 1925	Alfalfa	49.4	41.5	35.4
June 11, 1925	Alfalfa	49.1	48.3	35.4
June 11, 1925	Sweet clover	49.0	58.3	58.3
June 11, 1925	Sweet clover	49.0	59.0	59.1
June 11, 1925	Sweet clover	49.1	53.8	61.9

show a significant difference in this direction, which might conceivably be due to wounding the stems in cutting off the leaves, it would be of no practical importance, since the leaves can never be clipped from the stems in actual haymaking. On the other hand, every sample of soybeans showed a distinct difference, the stems with the leaves left on always showing a lower percentage of moisture than those with leaves removed. This difference was also observed to some extent in the behavior of the plants in drying. The soybean leaves which were attached to the stems became brittle two or three hours later than those which were cut off. The difference between the Manchu and Peking soybeans in 1924 was due to the fact that the Manchu soybeans bore pods two-thirds grown and hence dried much more slowly than the Peking soybeans in which the pods were just formed.

The data on the other crops are insufficient to permit of any conclusions as to their behavior. Alfalfa is the crop about which the most has been written concerning the leaves pumping water from the stems, and the above data alone are sufficient to suggest that this cannot be very important in practical alfalfa curing. But what about soybeans? In the shade their leaves seem to dry the stems. Is it then important to cure soybean hay in the shade? The other part of the theory we are discussing assumes that leaves which are dried by exposure to the sunlight are killed before they have had time to transpire a maximum of water from the stems. To test this it was necessary to compare clipped and normal stems dried in full sunlight. This was first done with alfalfa and sweet clover, soybeans not being available at the time. The "sun" samples were placed on a table, exposed to full sunlight, a clipped stem immediately adjacent to a normal stem. The "shade" samples were run in the same manner with a wooden shade suspended at some distance above the samples so that they were fully exposed to wind but not to any direct sunlight. Both sets of samples were weighed as soon as the leaves were brittle. The results of the first experiment are given in Table 2. These tests were started early June 19, 1925, a clear sunny day with a good breeze, and a maximum temperature of about 79°. Three samples are averaged for each trial.

TABLE 2.—*Effect of sun on drying of forage stems.*

Crop	Average number of hours exposure	Exposure	Percentage moisture in stems Normal	Leaves clipped off	Difference
Alfalfa	25.1	Shade	49.2	49.3	0.1
Alfalfa	5.7	Sun	48.3	45.2	3.1
Sweet clover	28.4	Shade	60.2	63.6	3.4
Sweet clover	6.2	Sun	55.5	60.1	4.6

There is nothing in these figures to suggest a difference in behavior in sun and shade. There is a suggestion that second year sweet clover is dried by the leaves somewhat as soybeans are, but the number of samples is too small to establish this, especially since only two of the four second year samples in Table 1 bear out the suggestion.

An interesting observation in connection with this test is that appearance is a very good guide to moisture content regardless of the rate of drying. An attempt was made to weigh the shade samples at the same stage of drying as the sun samples. The two series of alfalfa samples have nearly identical moisture contents, although one was left overnight and the other was dried in one day's midday sun. The shade sweet clover was weighed at 2:45 p. m., the day after the test started and notes made then said, "These samples are not as dry as the sun samples yesterday, but the leaves have clearly ceased to function in transpiration." The moisture determinations bore this out.

A more extensive experiment was carried out with alfalfa on July 1, averaging 12 samples in each group, 48 samples in all, and using various periods of exposure. The maximum temperature was 80° and the relative humidity 35 to 38. The results are given in Table 3.

TABLE 3.—*Percentage of moisture in alfalfa stems.*

Exposure	Normal	Leaves clipped off	Difference
Shade	70.5	68.5	2.0
Sun	58.9	61.4	2.5

In this experiment the stems with the leaves on exposed to the sun were slightly drier, while in the shade those with the leaves cut off were slightly drier. It is doubtful, however, whether either difference is significant. Certainly no support is lent to the idea that the leaves are killed by the sun before they have secured all the water that it is possible for them to secure from any available source.

On August 17, when soybeans at the hay stage were available, 13 pairs of samples were dried in full sunlight at a maximum temperture of 91°. When the leaves on the normal samples were brittle, which required 3 to 3.5 hours depending on the time of day, the average percentage of moisture in stems with the leaves left on was 58.6 and of those with the leaves removed 64.7, a difference of 6.1%. As before, every pair of samples showed a difference in this direction. The soybeans, therefore, behaved the same in the sun as they did in the shade, that is, the leaves withdrew some moisture from the stems. It has always been difficult to understand why a leaf which has been constantly exposed to the sun all summer should, when cut, suddenly become so tender that it is killed by sunlight while there is still water available from any source to keep it alive.

It would seem that so far as practical haymaking is concerned any effect of the leaves in transpiring water from the stems may be entirely disregarded. If it is the nature of the plant for the leaves to take water from the stems, they will do it in the sun or in the shade, and at least one important hay plant seems to show no such effect. The writer wishes to have it clearly understood, however, that this is in no sense a condemnation of curing hay in the windrow or cock. The loss of leaves and the damage to the quality of hay due to bleaching when legume hay is cured too long in the swath are abundant justification for putting hay in the windrow before the leaves are brittle. The practice is good. The writer merely wishes to point out that a particular theoretical benefit from the practice does not exist.

However, when some enthusiasts carry the theory so far as to claim, as at least one of them has done, that because of this supposed effect of transpiration hay will cure faster in the windrow than it will in the swath, they claim something which any farmer who has made hay knows is not usually the case. With very heavy lodged forage it is conceivable that turning the swath upside down, or rolling it into a windrow in such a manner that the stems instead of the leaves are exposed, might hasten the curing, since the stems dry much more slowly than the leaves, and ideally, they should be exposed to the sun and the leaves protected. The above experiments as well as all practical experience show conclusively that exposure to sunlight is favorable to rapid curing. It would seem that as a usual practice it would be best to allow hay to cure in the swath as long as possible without allowing the leaves to become brittle, using the tedder where desirable to loosen the swath and equalize the exposure, and then put the hay in the windrow or cock to complete curing. This is the common practice of the best farmers in putting up legume hay.

SUMMARY AND CONCLUSIONS

1. Experiments to determine whether the leaves of plants draw water from the stems in the process of curing into hay indicate that this occurs with some plants and not with others. Alfalfa stems dried at the same rate whether the leaves were attached or not. Soybean stems from which the leaves had been cut contained 3 to 7% more moisture than those similarly dried with the leaves attached. A total of 45 pairs of alfalfa samples were dried under various conditions and showed an average moisture content of 57% in the stems

dried normally and 56% in the stems having the same exposure but with the leaves removed. It is doubtful if this small difference is significant, but at least it is of no practical importance. It does emphasize that in alfalfa there is no tendency for the leaves to dry the stems. A total of 29 pairs of soybean samples showed an average of 58.4% moisture in the normally dried stems and 64.0% in similarly treated stems from which the leaves had been clipped. Every pair of soybean stems compared showed a difference in this direction.

2. Soybean leaves were as efficient in drying the stems when exposed to full August sunlight as when drying took place in the shade.

3. Drying was much more rapid in the sun, but whether dried in the sun or shade the appearance of the material was a fair guide to the moisture content.

4. In practical haymaking the most rapid curing will usually be secured by curing in the swath. Other considerations, such as bleaching and loss of leaves by shattering and crumbling, make it desirable to finish the curing of legume hay in the windrow or cock, but this bears no relation to curing the stems by transpiration through the leaves.

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RELATION OF TIME OF PLANTING CORN TO THE TIME OF SILKING, DENTING, AND SENESCENCE[1]

H. W. ALBERTS[2]

The most favorable time for planting corn varies with different localities, seasons, and varieties. Usual planting dates for the southern portion of the corn belt are earlier than those for the northern portion. In the northern portion planting is begun, however, when the soil and air temperatures are lower than they are at the beginning of planting time in the central and southern portions. Cool spring rains frequently retard the time of planting, and when cool weather follows immediately after planting there is a tendency for the kernels to rot in the ground. Early-maturing varieties develop more readily in cool weather than late-maturing varieties. From 1890 to 1900 a number of investigators at various experiment stations in the corn belt planted corn at different dates to determine the most favorable time for planting.

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[1] Contribution from the Department of Agronomy, University of Wisconsin, Madison, Wisc. Received for publication January 16, 1926.

[2] Formerly Instructor in Agronomy.

HISTORICAL

The following investigators found that development was retarded by planting too early. Georgeson, Burtis, and Otis (5)[3] reported that corn which was planted too early in Kansas was slow in coming up and rotted in the ground. Gardner (4) found that early planting required more cultivating and not unfrequently produced the lowest stand. Morrow and Hunt (12) stated that, in general, the earlier planting made the slower growth. While there was six weeks variation in planting, there was but three weeks variation in maturity.

Morrow and Bone (8) found that the earlier plats of kafir corn were blighted, while the plats which were planted later were not blighted at all. Foster (3) reported that while corn may be planted any time after the beginning of May without danger of seed rotting, no gain is made in yield or earliness of maturity by planting before the conditions of the soil and atmosphere are right. Morrow and Bone (7) found that late-planted corn matured in less number of days than early-planted corn.

Planting too late was also found to be undesirable. Hickman (6) reported that corn planted after May 14 in Ohio failed to come to full maturity. Williams and Welton (14) found that the moisture content was highest in late-planted corn. Similar results were obtained by Morrow and Gardner (9).

Knowledge of the relation of the time of planting to the time of silking, denting, and senescence may be an aid in determining the optium date of planting. The work reported by the writer was done at the Wisconsin Agricultural Experiment Station in the summer of 1925.

MATERIALS AND METHODS

Six varieties of dent corn and one variety of flint corn were used in the test. The varieties were: Northwestern Dent, an early variety grown at the Branch Experiment Station at Spooner, Wisconsin; Square Deal, an early yellow dent variety obtained from North Dakota; Golden Glow, a standard variety for Wisconsin; Cold Resistant Golden Glow, a strain developed from Golden Glow; Reid Yellow Dent, obtained from the Illinois Agricultural Experiment

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[3] Reference by number is to "Literature Cited," page 380.

TABLE 1.—*Relation of time of planting corn to the time of silking and denting.*

Date planted	Golden Glow		Cold Resistant Golden Glow		Northwestern Dent		Hastings Prolific		Reid Yellow Dent		Square Deal	
	Planting to silking *Days*	Silking to denting *Days*	Planting to silking *Days*	Silking to denting *Days*	Planting to silking *Days*	Silking to denting *Days*	Planting to silking *Days*	Silking to denting *Days*	Planting to silking *Days*	Silking to denting *Days*	Planting to silking *Days*	Silking to denting *Days*
May 2	86	40	77	42	72	42	119	—	96	39	77	37
May 9	79	40	70	42	65	42	112	—	89	39	70	37
May 16	72	40	63	42	58	42	105	—	82	39	63	42
May 23	70	36	65	40	52	40	98	—	75	39	65	40
May 31	68	39	58	40	58	40	91	—	75	41	58	40
June 6	68	37	61	39	65	—	—	—	—	—	—	—
June 13	—	—	—	—	—	—	—	—	—	—	—	—
June 20	62	40	62	38	58	—	81	—	70	—	58	37
June 27	63	—	58	—	51	37	74	—	70	—	55	38
July 5	63	—	56	—	44	37	77	—	68	—	51	37
July 11	61	—	56	—	—	—	—	—	70	—	56	—
July 18	67	—	59	—	45	—	—	—	—	—	54	—
July 25	—	—	—	—	—	—	—	—	—	—	—	—
August 1	59	—	58	—	49	—	—	—	—	—	—	—

Station; Hasting's Prolific, obtained from H. G. Hastings Co., Atlanta, Georgia; and Chippewa Flint, a very early white flint type grown at the Branch Experiment Station, Ashland, Wisconsin.

The corn was planted at weekly intervals beginning on May 2, and the last planting was made on August 1. A summary of the observations recorded throughout the summer is presented in Table 1.

EXPERIMENTAL

RELATION OF TIME OF PLANTING TO TIME OF SILKING

Varieties differed in the number of days required from the time of planting to the time of silking, the early-maturing varieties requiring the smallest number of days. Plants began to silk in order of date of planting, but the difference in date of silking was so small in the early plantings that it was negligible. This was especially noticeable in the varieties requiring a long growing season. Plantings of a given variety made at intervals later in the season required approximately the same number of days to reach the silk stage.

For example, Reid Yellow Dent corn planted on May 2 required 96 days to reach the silk stage and that which was planted on May 9 required only 89 days, whereas the time required for plantings made on June 20 and 27 and on July 11 to reach the silk stage was 70 days. Table 2 shows the relation of early planting dates to date of silking of four varieties of corn arranged in order of the length of time required for silking. Chippewa Flint required the smallest number of days and Hastings Prolific the largest number.

TABLE 2.—*Relation of early planting dates to dates of silking.*

Variety	Planting dates	Date of silking
Chippewa Flint	May 2, 9	July 7
Golden Glow	May 2, 9, 16	July 27
Reid Yellow Dent	May 2, 9, 16, 23	August 6
Hastings Prolific	May 2, 9, 16, 23, 31	September 14

The first two plantings of Chippewa Flint silked on July 7; the first three plantings of Golden Glow on July 27; the first four plantings of Reid Yellow Dent on August 6; and the first five plantings of Hastings Prolific on September 14. In each instance the silks appeared sooner on plants which were planted on May 2 than on those which were planted on the last-named date, but this difference was not very pronounced. The results were similar to those obtained by Morrow and Gardner (10) who found that the first four plantings (April 30, May 7, 16, and 23) of Murdock corn reached nearly their maximum height on the same date (July 26) and that the first three plantings of Burr's White reached nearly their maximum height on the same date.

RELATION OF TIME OF SILKING TO TIME OF DENTING

All the dent varieties which silked on the same date reached the dent stage on approximately the same date, regardless of whether they required a long or a short growing period prior to reaching the silk stage. The period required from the time of silking to the time of denting for the season of 1925 was approximately 40 days for both early and late plantings.

RELATION OF TIME OF PLANTING TO SENESCENCE

The beginning of maturity could be observed by noting the color of the husks on the lower side at the tip end of the drooping ear. At this place the outer husks did not cover the inner husks but left them exposed. When an area of about half an inch in diameter of this exposed portion of the inner husks had turned yellowish in color it indicated that the entire inner husks had begun to change color. Upon examining the kernels, it was found that when the inner husks were in this condition about 50% or more of the kernels had begun to dent. Beginning of change in color of the husk on the lower tip end of the ear was used as an index of denting during a part of the summer. This character, however, was not reliable late in the fall. When the weather was cool, denting began before the inner husks turned yellow.

Soon after the corn was fully dented the leaves dried up. Leaves on plants that were planted early dried up first. There was also a slight difference in the drying of leaves between the different varieties. The leaves of early varieties dried up sooner after denting than those of late varieties.

DISCUSSION

The results obtained indicate that the time of silking may be used as an index in comparing the degree of earliness or lateness of varieties, since the time required from the silk stage to the dent stage was nearly the same for all dent varieties tested. After the silk stage, it required approximately 40 days to reach the beginning of the dent stage.

Morrow and Gardner (11) planted two different varieties of corn in two different years and found the time from tasseling to glazing to be 42 days.

Azzi (1) stated that "between the heading stage and ripening (of cereals) there is on an average an interval of 40 days, and during these 40 days all growth processes are abridged."

Wallace (13) reported that there is very little change from one year to the next in the length of time between the appearance of the tassels and the roasting ear stage and that kernels glaze two weeks after the roasting ear stage.

A four-year summary of data obtained by Brown and Garrison (2) showed that the period from the time of silking to the time of ripening was 49 days for corn planted in April and 48 days for corn planted in May, June, or July.

SUMMARY

Early varieties required a shorter period of time to reach the silk stage than late varieties.

The period from the time of silking to the time of denting was approximately 40 days for both early and late varieties and for both early and late plantings for the season of 1925.

Late varieties retained green leaves longer after denting than early varieties.

Leaves of plants from earliest plantings dried up first.

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THE YIELD OF VARIOUS PASTURE PLANTS AT DIFFERENT PERIODS WHEN HARVESTED AS PASTURAGE AND AS HAY[1]

T. K. WOLFE[2]

The object of this experiment, which was started in 1921, was to determine the comparative value of certain pasture plants. The experiment was conducted on 1/160 acre plats. One-half of each plat was harvested as hay and the other half harvested with a lawn mower as growth demanded. The soil on which this experiment was conducted was a Hagerstown very fine sandy loam.

RESULTS

THE YIELD OF PASTURE PLANTS

The air-dried weights of pasturage were secured and the average yields for the three years of 1922 to 1924 are presented in Table 2. Orchard grass stands out as an excellent pasture grass in point of yield when it is compared with the yields of mixtures and of other pure grasses. However, there is frequently much criticism against the use of orchard grass in pastures. It has a bunching habit of growth which gives the pasture an unkept appearance and it, is apparently not as palatable as some other grasses. In spite of these objections orchard grass has many things in its favor. It gives a high yield of pasturage, will grow on thinner land than many other grasses, makes a good early spring and late fall growth, and does well during the hot, dry periods of the summer.

Although Kentucky bluegrass gave a lower yield than orchard grass, it is without a doubt the best all-round pasture plant for the rich soils of western Virginia. However, several years are required to obtain a good sod and for this reason it is usually seeded in mixtures. In this test Kentucky bluegrass and Canada bluegrass yielded the same amount of pasturage. Chemical analyses show that the former has a higher feeding value than the latter. Kentucky bluegrass gives a higher yield of dry matter on rich soil, but Canada bluegrass gives a higher yield on poor soil.

Perennial rye grass yielded less than Italian rye grass. The rye grasses are valuable for one year only but they usually persist for two years. Under favorable conditions perennial rye grass persists for several years, but the yield after the first year is usually small. These grasses will grow under almost any condition so long as a fair amount of water is available.

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[1] Contribution from the Vrginia Agricultural Experiment Station, Blacksburg, Va. Received for publication February 15, 1926.

[2] Agronomist.

Exceptionally good stands of Rhode Island bent grass, sheep's fescue, and red fescue were obtained. The two latter grasses yielded about the same. Sheep's fescue is a wonderful grass for seeding on extremely thin soils, since on such lands it will thrive where other grasses will not grow.

YIELD OF PASTURE PLANTS AT DIFFERENT PERIODS

The plats were not harvested at regular intervals, but the periods as shown in Table 1 are close approximations of the time. There is a tendency for a high yield to be produced from early spring to June 1 and for the yield to decrease thereafter, and the lowest yield to be obtained from August 15 to late fall. Red fescue and sheep's fescue yielded somewhat more in the late summer than during the early and mid-summer periods. Canada bluegrass yielded more in the late summer than at any other time. Attention should be called to the uniformly good yield throughout the season of orchard grass,

TABLE 1 *Total yield of pasture plants during 1922 to 1924, inclusive, harvested as pasturage at different periods.*

Kind of plant	Pounds of air-dried material per acre. From early spring to June 1	From June 2 to June 30	From July 1 to August 14	From August 15 to late fall
Kentucky bluegrass	1,200	660	680	510
Canada bluegrass	620	510	670	1,180
Orchard grass	3,970	2,080	2,160	1,180
Orchard grass and redtop	2,035	1,120	650	580
Orchard grass, redtop, alsike clover	2,900	1,320	880	530
Orchard grass, perennial rye grass, redtop	2,260	910	800	470
Kentucky bluegrass and white clover	1,140	940	780	740
Kentucky bluegrass, timothy, redtop, red clover	2,845	1,190	1,035	620
Perennial rye grass	2,380	760	780	530
Italian rye grass	4,300	1,780	545	130
Rhode Island bent grass	1,700	1,040	890	760
Tall meadow oat grass (2-year average)	2,325	1,680	880	640
Meadow fescue	1,300	1,250	590	250
Sheep's fescue	3,770	1,160	1,020	1,180
Red fescue	2,900	1,280	1,150	1,310

TABLE 2.—*The yields of different pasture plants grown alone and in combination, when harvested with a lawn mower and as hay, and the yield of pasturage expressed as percentage of the yield of hay.*

Crop	Pounds of air-dry material per acre								Percentage yield of pasturage (3-year average)
	1922		1923		1924		Average		
	Hay	Pasturage	Hay	Pasturage	Hay	Pasturage	Hay	Pasturage	
Kentucky bluegrass.	2,080	530	1,280	780	1,840	1,740	1,733	1,017	60.3
Canada bluegrass.	1,920	480	1,040	980	2,240	1,520	1,733	993	62.4
Orchard grass.	7,760	2,940	5,200	3,450	4,480	3,000	5,813	3,130	57.1
Orchard grass, redtop.	4,240	990	3,440	1,335	3,520	2,060	3,733	1,462	40.2
Orchard grass, redtop, alsike clover.	6,400	1,610	4,440	1,760	3,360	2,260	4,720	1,877	44.1
Orchard grass, redtop, perennial rye grass.	7,280	1,290	4,080	1,330	3,520	1,820	4,960	1,480	34.0
Kentucky bluegrass, white clover.	3,760	710	4,400	1,090	2,040	1,800	3,400	1,200	44.0
Kentucky bluegrass, timothy, redtop, red clover.	11,760	2,655	6,240	1,155	4,000	1,880	7,333	1,897	29.4
Perennial rye grass.	6,880	1,690	2,160	1,620	3,040	1,140	4,027	1,483	45.7
Italian rye grass.	7,600	4,255	720	1,300	2,800	1,200	3,707	2,252	93.1
Rhode Island bent grass.	4,320	1,340	4,320	1,190	2,640	1,860	3,760	1,463	43.0
Meadow fescue.	5,840	1,730	1,840	1,100	3,120	560	3,600	1,130	35.8
Sheep's fescue.	3,120	2,060	6,160	3,170	2,440	1,900	3,907	2,377	65.1
Red fescue.	6,400	2,000	6,080	2,400	2,080	2,240	4,853	2,213	59.5
Tall meadow oat grass.	——	——	6,080	3,445	5,840	2,080	5,960	2,763	30.8

sheep's fescue, red fescue, and of the mixture of Kentucky bluegrass, timothy, redtop, and red clover, except during the late summer period.

A common practice in western Virginia, when it is desirable to turn land into pasture, is to seed a mixture of Kentucky bluegrass, timothy, redtop, and red clover and harvest the crop as hay for two or three years and then use it as a pasture. On very productive land the mixture is used without Kentucky bluegrass and in four or five years a good bluegrass sod is obtained from the natural encroachment of the bluegrass. The bluegrass sod can be secured more quickly when the bluegrass seed is placed in the mixture at seeding time.

It would seem from a study of the data that a mixture of Kentucky bluegrass, orchard grass, redtop, and white clover should make a very satisfactory combination for the production of pasturage in western Virginia. This mixture has proved very practical under farm conditions.

COMPARATIVE YIELDS OF PASTURE PLANTS HARVESTED AS PASTURAGE AND AS HAY

The comparative yields of hay and pasturage are shown in Table 2 In every case the hay yields are greater than under pasturage conditions. On the whole, the yield of pasturage is from 40 to 65% of that of hay.

SUMMARY

The growth of pasture plants was more luxuriant in the cool, moist spring season than in the hot, dry summer season.

Orchard grass gave exceptionally good yields of pasturage. Kentucky bluegrass is the leading pasture plant in western Virginia, but several years are required for the establishment of a good sod. Sheep's fescue yielded well and is an outstanding pasture plant for thin soils.

A mixture of pasture plants, such as Kentucky bluegrass, orchard grass, redtop, and white clover, is better than any of the plants tested when grown alone. An association of these plants has proved practical under farm conditions, since the production is more continuous than that of any one of the plants when grown alone.

On the whole, the yield of pasturage was from 40 to 65% of the yield of hay.

A COMPARISON OF SWEET CLOVER TYPES WITH RESPECT TO COUMARIN CONTENT, NUTRITIVE VALUE, AND LEAF PERCENTAGE[1]

L. E. Kirk[2]

The object of this investigation was to secure comparable data on the coumarin content and average percentage composition of several distinct types of sweet clover. The plan also included a study of leaf percentages and a comparison of the nutritive value of leaf and stalk. Determinations were made on three cuttings from the same variety test plats, one in the fall of the year that the clover was sown, and a first and second during the second season's growth. A comparison was therefore possible on the basis of the three cuttings.

The sweet clover samples were taken from the plats at time of cutting for hay and the plants dried to constant weight in the laboratory. The leaves were removed from the stalks and the weights of leaf and stalk recorded. The material was then forwarded to Dr. Frank T. Shutt, Chief of the Division of Chemistry, Central Experimental Farm, Ottawa, through whose generous cooperation the chemical determinations were made.

MATERIALS

Eight strains of sweet clover (five white blossom and three yellow), representing five distinct types, were used in the experiment. These five types are designated as Arctic, *Melilotus alba*, Suaveolens, *Melilotus officinalis*, and Daghestan.

Arctic sweet clover is an early, hardy, and fine-stemmed variety of *Melilotus alba*. Determinations were made with material of the mother variety, Sask. No. 439, and also with material of two single plant selected strains, Sask. No. 662 and Sask. No. 664. Since these three belonged to a single type and were similar in chemical composition, it was thought advisable to average the results.

Melilotus alba differs from the type designated as Arctic in being taller, coarser, and later in maturing. The values for two sets of determinations on material of this type were averaged. One of these was grown from commercial seed, the other being a promising selection out of common white sweet clover recorded as Sask. No. 432.

Suaveolens, Sask. No. 446, is a very distinct type of yellow sweet clover. It differs markedly from common yellow blossom in several respects, one of the most striking being an upright habit of growth the first season. A strain of this clover, developed at this institution, has been given the variety name Zouave.

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[1] Contribution from the Field Husbandry Department, University of Saskatchewan, Saskatoon, Sask., Can. The chemical determinations were made by the Division of Chemistry, Central Experimental Farm, Ottawa. Received for publication February 20, 1926.

[2] Professor of Field Husbandry.

Melilotus officinalis, Sask. No. 442, is a selected strain of common yellow blossom sweet clover.

Daghestan resembles *M. officinalis* in that the first year's growth is prostrate. It is, however, a very distinct variety which is readily distinguished from the common yellow blossom type.

The samples for analyses were taken from 1/20 acre variety test plats. These formed a continuous series located on a uniform soil type which may be described as medium clay loam. The fall cutting was made in September, 1922; and the first cutting of the second season on June 25, 1923, in the early blossom stage of growth, and the second cutting of the second season in August, 1923, when the plants were in full bloom.

The information contained in Table 1 on stand, height of plants at time of cutting, and yield of cured hay per acre is presented so as to give the reader an idea of the vegetative growth when the samples were taken. The large yield of cured hay secured in 1923 was due to exceptionally favorable growing conditions and to the clover being grown without a nurse crop. Hay yields were calculated from the green weights by adding 15% moisture to the average dry matter content.

TABLE 1.—*Percentage stand, height of plants at time of cutting, and yield of cured hay per acre from sweet clover variety test plats.*

Variety	Percentage stand	Height of plants in inches		Yield of cured hay in pounds per acre	
		First cutting, 1923	Second cutting, 1923	Fall cutting, 1922	Average first and second cuttings, 1923
Arctic, Sask. No. 439......	98	30	16	1,410	6,265
Arctic, Sask. No. 662......	100	25	15	1,396	6,231
Arctic, Sask. No. 664......	100	30	15	1,927	6,607
Melilotus alba, (commercial. seed)...........	100	26	20	1,942	8,424
Melilotus alba, Sask. No. 432	98	28	21	2,159	8,549
Suaveolens, Sask. No. 446...	96	30	18	2,932	6,303
Melilotus officinalis, Sask. No. 442............	100	22	16	1,275	6,540
Daghestan, Sask. No. 447...	100	25	20	980	8,926

DISCUSSION OF DATA

Forty-eight determinations in all were made for each plant constituent. From a perusal of the data in Table 2, it is evident that the differences between the sweet clover types are relatively small.

It was thought justifiable, therefore, to group the values in various ways so as to obtain an average figure for each constituent which would represent as many determinations as possible as a basis of comparison for yellow and white sweet clover, leaf and stalk, and cuttings made at different stages of growth. These data are represented in Tables 3, 4, and 5. Table 6 gives the percentage of leaf in the air-dry material for each of the three cuttings. Tables 7 to 12, inclusive, give the analysis for each constituent. These last contain the original data from which the composite tables were constructed.

In cases where the values for leaf and stalk are combined, as in Tables 2 and 4, the figures are adjusted to actual percentage of leaf and stalk. For example, by multiplying the percentage of protein in the leaf by the leaf percentage and the percentage of protein in the stalk by the percentage of stalk and adding these together, a value is obtained which represents the percentage of protein in the whole plant.

Table 2 summarizes the data for each sweet clover type. The values for leaf and stalk are given separately, each figure being an average of the three cuttings. These figures are then combined as described in the preceding paragraph. There appears to be no im-

TABLE 2.—*Comparison of average percentage composition of sweet clover types.*[a] The upper figure is for leaf, the second for stalk, and the third the average of the two. (Moisture-free basis.)

	Number of determinations	Percentage of Leaf	Dry matter	Protein	Carbohydrates	Ether extract	Ash	Fiber	Coumarin
Arctic.	9	49.99	91.61	29.34	44.82	5.20	11.30	9.33	0.78
	9			17.72	34.97	2.91	8.40	36.00	0.83
	18			23.53	39.89	4.05	9.85	22.66	0.80
Melilotus alba.	6	50.01	91.45	29.79	43.63	5.69	11.14	9.74	0.94
	6			17.69	34.81	3.32	8.66	35.34	0.84
	12			23.74	39.22	4.50	9.90	22.54	0.89
Suaveolens	3	47.86	91.86	28.21	43.14	6.34	12.89	9.38	0.81
	3			16.08	36.43	3.92	8.88	34.70	0.80
	6			21.88	39.64	5.07	10.80	22.58	0.80
Melilotus officinalis....	3	54.34	92.12	26.83	44.96	7.50	11.56	10.16	0.86
	3			18.89	34.91	4.41	8.61	33.17	1.11
	6			23.21	40.37	6.09	10.21	20.67	0.98
Daghestan....	3	53.99	91.24	29.72	41.52	6.87	11.95	10.93	0.78
	3			17.33	34.58	3.48	9.88	34.72	0.75
	6			24.02	38.33	5.31	11.00	21.87	0.76
Average......	24	51.24	91.66	28.78	43.61	6.32	11.57	9.91	0.83
	24			17.54	35.14	3.61	8.89	34.79	0.87
	48			23.30	39.48	5.00	10.26	22.04	0.85

[a] The average values are adjusted to actual percentage of leaf and stalk.

portant difference in any respect between any two of the sweet clover types. This is more fully evident from Tables 7 to 12, in which the values for each determination are given separately for each of the three cuttings.

Table 3 is constructed from Table 2 by averaging the values for white sweet clover and also for the yellow. The comparison shows that there is no significant difference in composition between the yellow and white blossom, except perhaps in ether extract, yellow being consistently higher for leaf and stalk in both first and second cuttings in 1923. (See Table 10.)

The most noteworthy features of the data in Table 3 are the high figures for content of protein and ether extract. A comparison with the protein content of alfalfa as given in the appendix of Henry and Morrison's "Feeds and Feeding" (1922 edition) serves to emphasize this point. The average value for sweet clover is 23.33% as compared with 16.3% for alfalfa. Considering that the protein value for sweet clover is the result of 48 determinations and in view of the consistency of the results (Table 8), the comparison is all the more striking. For ether extract the average is 4.88% as compared with 2.52% for alfalfa. (See Table 10.) The values for protein and ether extract in alfalfa as given by Henry and Morrison were calculated to the moisture-free basis for purposes of comparison.

TABLE 3.—*Average percentage composition of white and yellow sweet clover*

Moisture-free basis.

					Percentage of				
	Number of determinations	Leaf	Dry matter	Protein	Carbohydrates	Ether extract	Ash	Fiber	Coumarin
White	30	50.00	91.53	23.63	39.56	4.28	9.87	22.60	0.85
Yellow	18	52.06	91.74	23.03	39.45	5.49	10.67	21.71	0.85
Average	48	51.03	91.63	23.33	39.50	4.88	10.27	22.15	0.85

In Table 4 the data for all of the sweet clover types are averaged for each cutting. The fall cutting is high in ratio of leaf to stalk, coumarin content, and in carbohydrates. Tables 6, 7, and 9 show the results to be consistent for all varieties. The amount of fiber increases and the amount of ash decreases from the first to the third cutting. The results, however, are not fully consistent for all varieties. (See Tables 11 and 12.) No other important differences are apparent. It will be noted that the values for protein are almost identical for the three cuttings.

Table 5 shows the leaves of sweet clover, which constitute approximately 50% of the plant, to contain about two-thirds more protein than the stalk, almost twice as much ether extract, and considerably

TABLE 4.—*Average percentage composition of sweet clover varieties for each of three cuttings.*[a]

Moisture-free basis.

Cutting	Number of determinations	Percentage of							
		Leaf	Dry matter	Protein	Carbohydrates	Ether extract	Ash	Fiber	Coumarin
Fall cutting, 1922	16	64.19	91.46	22.89	43.66	4.52	11.74	17.54	1.11
First cutting, 1923	16	44.24	91.99	23.03	37.54	5.59	10.09	23.75	0.62
Sec'd cutting, 1923	16	45.28	91.48	22.83	37.59	4.79	9.55	25.23	0.81

[a] The values are adjusted to actual percentage of leaf and stalk.

TABLE 5.—*Average percentage composition of sweet clover leaf and stalk.*

Moisture-free basis.

	Number of determinations	Percentage of					
		Protein	Carbohydrates	Ether extract	Ash	Fiber	Coumarin
Leaf[a]	24	28.78	43.61	6.32	11.57	9.91	0.83
Stalk	24	17.54	35.14	3.61	8.89	34.79	0.87

[a] Average leaf percentage = 51.24

TABLE 6.—*Leaf percentage of different types of sweet clover.*

Material air-dried to constant weight in laboratory.

	Fall cutting, 1922	First cutting, 1923	Second cutting, 1923	Average of 3 cuttings
Arctic	63.32	42.58	44.07	49.99
Melilotus alba	58.34	46.32	45.38	50.01
Suaveolens	56.73	43.36	43.48	47.86
Melilotus officinalis	71.51	43.80	47.71	54.34
Daghestan	71.07	45.13	45.77	53.99
Average	64.19	44.24	45.28	51.24

TABLE 7.—*Average percentage coumarin content of sweet clover.*

Moisture-free basis.

	Fall cutting, 1922	First cutting, 1923	Second cutting, 1923	Average of 3 cuttings	Average of first and second cutting 1923
	Leaf				
Arctic	0.96	0.73	0.65	0.78	0.69
Melilotus alba	0.88	0.96	0.97	0.94	0.96
Suaveolens	0.86	0.67	0.90	0.81	0.78
Melilotus officinalis	0.81	0.82	0.95	0.86	0.88
Daghestan	0.88	0.48	0.98	0.78	0.73
Average	0.88	0.73	0.89	0.83	0.81
	Stalk				
Arctic	1.37	0.43	0.68	0.83	0.55
Melilotus alba	1.33	0.39	0.79	0.84	0.59
Suaveolens	1.32	0.28	0.81	0.80	0.54
Melilotus officinalis	1.37	1.04	0.92	1.11	0.98
Daghestan	1.35	0.43	0.46	0.75	0.44
Average	1.35	0.51	0.73	0.87	0.62

TABLE 8.—*Average percentage protein content of sweet clover.*

Moisture-free basis.

	Fall cutting, 1922	First cutting, 1923	Second cutting, 1923	Average of 3 cuttings
		Leaf		
Arctic	24.68	30.29	33.05	29.34
Melilotus alba	25.52	30.76	33.12	29.79
Suaveolens	23.86	28.54	32.24	28.21
Melilotus officinalis	23.57	27.55	29.36	26.83
Daghestan	26.23	31.34	31.59	29.72
Average	24.77	29.70	31.87	28.78
		Stalk		
Arctic	20.34	17.92	14.89	17.72
Melilotus alba	18.74	19.30	15.04	17.69
Suaveolens	17.99	14.16	16.09	16.08
Melilotus officinalis	21.33	18.91	16.44	18.89
Daghestan	19.24	18.40	14.36	17.33
Average	19.53	17.74	15.36	17.54

TABLE 9.—*Average percentage carbohydrate content of sweet clover.*

Moisture-free basis.

	Fall cutting, 1922	First cutting, 1923	Second cutting, 1923	Average of 3 cuttings
		Leaf		
Arctic	47.82	43.50	43.14	44.82
Melilotus alba	46.54	43.64	40.70	43.63
Suaveolens	47.93	41.51	39.98	43.14
Melilotus officinalis	46.28	42.81	45.78	44.96
Daghestan	45.05	36.93	39.58	40.52
Average	46.72	41.68	41.84	43.41
		Stalk		
Arctic	34.91	34.97	35.03	34.97
Melilotus alba	35.58	34.41	34.45	34.81
Suaveolens	39.11	35.56	34.62	36.43
Melilotus officinalis	37.62	33.02	34.10	34.91
Daghestan	38.32	33.28	32.15	34.58
Average	37.11	34.25	34.07	35.14

more carbohydrates and ash. The stalks are more than three times as high in fiber. Coumarin content is practically the same in the leaf and stalk.

Table 6 shows a relatively high leaf percentage in the fall cutting with appreciable differences for the different types of sweet clover, but only small differences for the first and second cuttings of the second year's growth. The petioles were included in the weight of the leaves. The average leaf percentage for all types of sweet clover is 51.24.

Tables 7 to 12 present the results of analyses in detail for each plant constituent. Table 7 shows the content of coumarin to be

TABLE 10.—*Average percentage ether extract content of sweet clover.*

Moisture-free basis.

	Fall cutting, 1922	First cutting, 1923	Second cutting, 1923	Average of 3 cuttings
		Leaf		
Arctic	5.55	5.86	4.18	5.20
Melilotus alba	5.25	5.44	6.37	5.69
Suaveolens	4.85	6.51	7.75	6.37
Melilotus officinalis	5.77	9.40	7.32	7.50
Daghestan	5.05	7.97	7.60	6.87
Average	5.29	7.04	6.64	6.33
		Stalk		
Arctic	3.42	2.87	2.43	2.91
Melilotus alba	3.20	3.89	2.88	3.32
Suaveolens	2.91	4.68	4.16	3.92
Melilotus officinalis	3.70	6.17	3.37	4.41
Daghestan	2.36	4.57	3.52	3.48
Average	3.12	4.44	3.27	3.61

TABLE 11.—*Average percentage ash content of sweet clover.*

Moisture-free basis.

	Fall cutting, 1922	First cutting, 1923	Second cutting, 1923	Average of 3 cuttings
		Leaf		
Arctic	13.18	10.21	10.52	11.30
Melilotus alba	12.86	9.78	10.77	11.14
Suaveolens	13.74	13.89	11.05	12.89
Melilotus officinalis	14.87	8.96	7.84	10.56
Daghestan	14.31	11.41	10.14	11.95
Average	13.79	10.85	10.06	11.57
		Stalk		
Arctic	7.65	9.05	8.51	8.40
Melilotus alba	7.47	8.94	9.58	8.66
Suaveolens	7.77	9.26	9.60	8.88
Melilotus officinalis	8.46	9.22	8.16	8.61
Daghestan	8.96	10.95	9.74	9.88
Average	8.06	9.48	9.12	8.89

markedly higher in stalk than in leaf for the fall cutting. The range in either case is not large. A greater range of differences is apparent between the several sweet clover types in the data for first and second cuttings. It is doubtful, however, if they should be interpreted as significant, since in most cases they are within the limits set by the accuracy for the analytical method for coumarin determination.

The average protein content does not differ significantly for the different sweet clover types. In leaf, it is uniformly greatest for the second cutting of the second year's growth. With respect to stalk the reverse is true, except in the case of Suaveolens where the first cutting of the second year is least.

TABLE 12.—*Average percentage fiber content of sweet clover.*

Moisture-free basis.

	Fall cutting, 1922	First cutting, 1923	Second cutting, 1923	Average of 3 cuttings
		Leaf		
Arctic	8.78	10.13	9.11	9.34
Melilotus alba	9.84	10.36	9.03	9.74
Suaveolens	9.62	9.55	8.98	9.38
Melilotus officinalis	9.51	11.28	9.70	10.16
Daghestan	9.36	12.35	11.09	10.93
Average	9.42	10.73	9.58	9.91
		Stalk		
Arctic	33.68	35.18	39.15	36.00
Melilotus alba	34.54	33.44	38.04	35.34
Suaveolens	32.22	36.34	35.53	34.70
Melilotus officinalis	28.89	32.68	37.93	33.17
Daghestan	31.12	32.80	40.23	34.72
Average	32.09	34.09	38.18	34.79

The carbohydrate content is somewhat greater in the leaves than in the stalk. It is also higher in the fall cutting than in the cuttings of the second year's growth. There is no consistent difference between the different sweet clover types in the amount of this constituent.

The amount of ether extract is much greater in the leaves than in the stalks. The yellow blossom varieties contain a larger quantity than the white, common yellow, *M. officinalis*, having the highest percentage. Variation between types is considerable.

It should be pointed out that the data under the heading "ether extract" are not to be interpreted as representing percentages of true fat or oil. The "extract" is largely made up of resins, gums, chlorophyll, etc., the percentage of true fat being comparatively small.

There are considerable differences in ash content of leaf, but less in respect to stalk. The average amount of ash is approximately 30% greater in the former than in the latter. Different sweet clover types show no consistent differences.

In the fall cutting there is little difference in the fiber content for the different sweet clover types. The other cuttings are slightly more variable. As would be expected, the stalks contain very much more fiber than the leaves.

TESTS OF STRAINS OF RED CLOVER FROM VARIOUS SOURCES[1]

E. J. DELWICHE[2]

INTRODUCTORY

This is a progress report of a test of red clover strains from various parts of the world where red clover is grown for seed purposes. The tests were undertaken as a cooperative experiment between the Office of Forage Crops Investigations, United States Department of Agriculture, and the Department of Agronomy of the Wisconsin Experiment Station.

Clover seed for the experiments and small sums for labor bills in certain years were supplied by the Bureau. Most of the labor and land for the tests were furnished by the state at the branch experiment stations.

General plans were arranged between Dr. A. J. Pieters, representing the Department of Agriculture, and the writer, who represents the Department of Agronomy, Wisconsin Experiment Stations, and who also had immediate charge of the tests.

PURPOSE OF RED CLOVER INVESTIGATIONS

The purpose of this investigation was to determine whether or not clover seed of foreign origin is suitable for the rigorous climatic conditions that obtain in such regions as Wisconsin. The immediate incentive was the fact that immediately after the close of the world war, and for several years thereafter, large quantities of red clover seed were shipped to the United States and put on our markets at prices considerably lower than domestic seed sold for at the time. Similar tests were undertaken and are now in progress in practically all the northern states where red clover is grown for hay, seed, and pasture.

IMPORTATIONS OF RED CLOVER SEED INTO THE UNITED STATES

Table 1 gives the quantities of red clover seed imported from 1919 to 1925, inclusive. It will be noted that when such large quantities of seed of such an important crop as red clover are sown, it is essential that such seed be suited to our conditions. Red clover is a valuable crop in itself for furnishing forage and pasture. Besides, the crop has a most important influence on the yields of crops that grow with it in rotation, since it helps in maintaining a proper supply of nitrogen on the farms where it is grown.

[1] Contribution from the Department of Agronomy, Wisconsin Agricultural Experiment Station, Madison, Wisc. Published with the approval of the Director. Received for publication February 23, 1926.

[2] Professor of Agronomy.

REVIEW OF OTHER TESTS WITH RED CLOVER STRAINS

A cursory review of reports and bulletins containing accounts of red clover investigational work in the north-central states shows much unanimity of conclusions relative to the value of foreign seed. Cox and Megee in Michigan, Wyancko in Indiana, and Arny in Minnesota are in accord in the statement that most European-grown clover seed is not sufficiently hardy to survive the frequent severe winters common to this section of the country. When severe freezing occurs in late winter with the ground wholly or partly bare of snow, only the very hardiest red clover strains can survive in sufficient stands for a normal crop of hay.

Previous work done by the Wisconsin Department of Agronomy indicated that European clover strains are not sufficiently hardy for Wisconsin conditions and contiguous states. In 1906, some 20 strains of red clover were sown at the Iron River substation in northern Wisconsin. Similar tests were made in cooperation with farmers near Ashland, Wisconsin. Results obtained then were unfavorable to imported red clover seed.

LOCATION AND PLAN OF EXPERIMENTS

The Wisconsin red clover strain experiments were planned to test under three different climatic and soil conditions. The northernmost test was at the branch experiment station near Ashland, Wisconsin. This station is in latitude 46° 35′ at an elevation above sea level of 648.4 feet. The station farm proper is less than a mile distant from Chequamegon Bay, an arm of Lake Superior. Very low minimum temperatures have been recorded here (—41½°F.). Generally, there is not much freezing and thawing. The snowfall is moderate, nevertheless, the ground usually remains covered until the latter part of March. The soil type is Superior red clay, one of the most retentive for water of any in the state. Red and alsike clover and alfalfa thrive on this soil, which is quite high in calcium and magnesium carbonate and potassium, but not high in phosphorus. The red clay section near Lake Superior is about the best red clover area in the state.

The Marshfield branch station, the location of another set of test plats, is in latitude 44° 4′ and an elevation of 1,283 feet above sea level. It is about 150 miles south of Lake Superior and 125 miles west of Lake Michigan. Probably the influence of these bodies of water on the climate is slight. Minimum temperatures of around 40° below zero have been recorded. Both rainfall and snow are heavier than at Ashland. There is more tendency to bare ground in Marshfield and much freezing and thawing in April. Winter grain kills out more than at Ashland. The soil, which is a gray silt loam (Colby silt loam) derived from non-calcareous rocks, is very retentive of water. It heaves quite badly in poorly drained spots. The Colby silt loam is relatively low in lime but well supplied with other essential mineral elements. Clover produces big crops in favorable years. Lime is necessary for alfalfa.

The Spooner branch station is in latitude 45° 51′ about 60° miles south of Lake Superior and 180 miles west of Lake Michigan. The elevation is 1,104 feet above mean sea level. Meteorological records for Spooner show considerably greater temperature range than for Ashland and Marshfield, with a maximum of 140° and a minimum of —49°. The average precipitation is about 35 inches, very similar in amount to Marshfield and at least 5 inches greater than for Ashland. Springs open up earlier than at Marshfield or Ashland. Snow usually covers the ground until April, but frequently the ground is bare with temperatures several degrees below zero. Seeding begins in April, even though zero weather has occurred during that month.

The soil at Spooner is a reddish sandy loam known as Plainfield sandy loam. It is underlaid with gravel from a depth of approximately 15 inches. The permanent water table is about 20 feet below the surface. This soil, in the virgin condition, is fairly well supplied with mineral soil elements, but is low in organic matter. Land which was cropped for about ten years shows a response to liming for alfalfa. Winter wheat kills out here as a rule. There is no heaving of the soil.

The plats, which ranged in area from 1/60 to 1/20 acre, were arranged in duplicate. The width for different tests ranged from 4 to 6 feet with an 18-inch alley between plats. Borders were cut out all around at harvest to square the fields.

At Ashland the clover was sown in either spring wheat or oats and following peas. At Spooner the nurse crop used was oats in all instances, the grain crop usually following soybeans, corn, or potatoes. In the Marshfield tests the clover was sown in oats or wheat following corn, soybeans, or peas.

At Marshfield and Ashland seeding was always done with a grain drill with clover seeding attachment. As a rule, the clover was broadcasted in front of the drill and thus covered with the chains. In all cases, the seeding was done after the grain was sown and at right angles to the grain drill. Guards to prevent the wind from blowing the clover seed in the wrong plats were used at Spooner and Marshfield.

TABLE 1.—*Pounds of red clover seed imported into the United States, 1919 to 1925, inclusive.*

Reported by the Seed Testing Laboratory, Bureau of Plant Industry, U. S. D. A., under date of December 22, 1925.

Country	1919	1920	1921	1922	1923	1924	1925
Canada	754,200	98,300	279,900	449,200	5,100	333,100	151,900
Chili			79,500	670,800	12,200	778,700	232,600
Czecho Slovakia			132,000	374,100		264,700	45,300
England	56,000	1,786,000	209,400		44,800	3,999,000	281,000
France	83,500	9,253,200	15,224,600	2,947,800	169,800	17,610,300	4,932,600
Germany		195,300	44,000	2,851,600	84,000	126,200	432,600
Italy	153,800	7,808,900	221,900	2,053,800		999,400	151,100
Scotland							154,400
Other countries	3,400	126,200	142,000	1,043,900	132,000	617,500	159,800
Total	1,050,900	19,267,900	16,333,300	10,391,200	447,900	24,728,900	6,541,300

TABLE 2.—*Winter hardiness tests of strains of red clover expressed in percentage of stand, comparing seed imported from Italy with seed of American origin, 1920 to 1921.*

Station	Italian, U.S.D.A. No. 1819		Italian, U.S.D.A. No. 2006		South Dakota, U.S.D.A. No. 2019		Ohio, U.S.D.A. No. 2020		Home grown		North Dakota, U.S.D.A. No. 1809	
	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring
Ashland	100	10	100	10	100	90	100	90	100	90	100	90
Marshfield	90	0	90	0	80	45	90	40	—	—	93	30
Spooner	100	0	100	0	100	95	100	95	100	95	100	95

At Spooner usually the same plan was used as at the other stations, except in a few cases when the wheelbarrow seeder with guards was used.

The rate of seeding used was 15 pounds per acre for 90% germination. Proportionately more seed was used for lower germinations.

DISCUSSION AND TABULATIONS OF RESULTS

THE 1920 TO 1921 EXPERIMENTS

The results obtained at three different locations, while not alike in all details, are similar in general trend. There was winterkilling at all the stations for all varieties, but less at Ashland than elsewhere. This test indicated that the Italian red clover is not adapted to withstand the severest Wisconsin winters.

THE 1921 TO 1922 EXPERIMENTS

In 1921, the red clover hardiness test was made to include seed from France, Bohemia (Czecho Slovakia), Idaho, and Wisconsin. Unfortunately, no Italian seed was sown that year. The results are given in Table 3.

TABLE 3.—*Winter hardiness, disease resistance, and yield tests of red clover, comparing seed of foreign and American origin, 1921 to 1922.*

Source of seed	Spooner Station				Ashland Station		
	Stand		Disease resistance	Yield per acre	Stand		Yield per acre
	Fall	Spring			Fall	Spring	
	%	%		*Pounds*	%	%	*Pounds*
Wisconsin	80	75	Fair	3,289	80	80	3,960
France	80	80	Excellent	3,092	70	68	3,899
Ohio	80	75	Fair	3,690	60	60	3,876
Bohemia	30	25	Fair	——[a]	55	55	3,220
Idaho	85	80	Fair	2,867	60	60	3,575

[a] Plowed up on account of English plantain.

No appreciable differences were noted between the various seed stocks from the standpoints of yield and winterkilling. There was considerable mildew on all varieties, except the French strain on which the disease was almost entirely absent.

At Spooner no yield determinations were made with the Bohemian clover because the field had to be plowed up because of a heavy infestation of buckhorn or English plantain.

The fact that there was a good snow covering throughout the winter no doubt accounts for the absence of winterkilling.

THE 1922 TO 1923 EXPERIMENTS

The tests for 1922 to 1923 were greatly expanded. Red clover seed from over 20 different sources was sown at the three branch stations. Reference to Table 4 shows the sources of seed supply.

TABLE 4.—*Winter hardiness, disease resistance, and yield tests of red clover, comparing seed of foreign and American origin, 1922 to 1923.*

Variety No.	Source of seed	Winterkilling			Mildew at	Yield per acre		
		Ashland	Marshfield	Spooner	Ashland	Ashland	Marshfield	Spooner
		%	%	%	%	*Tons*	*Tons*	*Tons*
2156	Australia	0	5	15	10	3.52	1.5	2.2
2055	Chile	25	10	77	5	4.03	1.5	1.9
2217	Chile	10	0	27	4	4.3	1.7	1.5
2202	France	10	4	60	10	3.05	1.7	1.9
2214	Hamburg	0	0	35	10	2.97	1.5	2.1
54492	Italy	32	—	75	10	1.5	—	1.4
2220	Idaho	10	—	17	20	2.1	—	2.4
2138	Tennessee	3	0	27	20	2.59	1.7	2.1
2216	Bohemia	5	0	30	10	2.69	1.4	1.8
2142	Chile	10	0	70	7	3.12	1.6	1.9
54456	France	10	3	60	7	2.65	1.5	2.0
2215	France	5	-	62	7	2.72	1.5	1.7
2218	North Germany	15	0	25	7	3.27	1.6	2.1
54779	Italy	10	—	7.3	5	1.57	--	1.6
2135	Ohio	0	0	13	20	3.07	1.4	2.3
54467	Wales	5	0	65	5	2.85	1.6	1.8
2121	Bohemia	0	4	27	4	3.64	1.5	2.4
2203	Chile	2	5	17	3	3.68	1.7	2.8
54493	France	0	6	5.3	5	3.19	1.4	2.1
2213	West France	10	1	55	5	2.95	1.4	2.0
2219	Hungary	2	2	47	4	3.54	1.4	2.1
2212	Italy	10	0	65	4	2.10	1.6	1.5
2148	Oregon	0	9	55	20	2.64	1.6	1.8
2221	Wisconsin	0	0	20	18	3.07	1.6	2.0
54905	Poland	0	0	27	3	3.60	1.5	2.4
2225	Bohemia	2	0	50	3	3.31	1.6	1.7
54728	Italy	10	—	75	3	1.71	—	1.0
54708	Finland	0	—	15	15	1.40	—	1.5
54889	Holland	0	—	13	10	3.22	—	2.4

An examination of the data in Table 4 shows considerable winterkilling for certain clover strains at Ashland and Spooner, but practically no winter injury at Marshfield. At Ashland there was no winter injury noted worth mentioning for the American strains. On the other hand, most clover of European origin more or less winterkilled. One Italian strain killed to 32%. At Spooner all varieties killed to a considerable extent. The American strains suffered to a slight extent only, whereas the Italian strains winterkilled. Results there confirm previous conclusions regarding the nonhardiness of most foreign-grown clover seed.

THE 1923 TO 1924 EXPERIMENTS

Clover strain tests were put in this season at the three branch stations, but unfortunately, the Spooner test was on a field quite

TABLE 5.—*Winter hardiness, disease resistance, and yield tests of red clover, comparing seed of foreign and American origin, 1923 to 1924.*

Variety No.	Source of seed	Winterkilling Ashland %	Winterkilling Marshfield %	Winterkilling Spooner %	Diseased plants Ashland %	Diseased plants Marshfield %	Yield per acre Ashland *Tons*	Yield per acre Marshfield *Tons*
2156	Austria	0	0	4.5	Trace	0	1.35	2.11
54467	England	0	0	44	Trace	0	.93	2.1
54493	France	0	0	—	5	—	1.68	—
2219	Hungary	0	0	44	Trace	—	1.30	—
2148	Oregon	0	0	60	Trace	Trace	1.21	1.8
54905	Poland	0	0	68	Trace	4	1.46	2.7
2225	Bohemia	0	0	45	Trace	Trace	1.36	1.9
2222	Wisconsin	0	0	—	Trace	—	1.41	—
2236	Italy	0	0	80	25	4	.73	1.4
2252	England	0	0	56	2	0	1.13	1.9
2253	England	0	0	45	Trace	Trace	1.24	1.8
2254	Tennessee	0	0	64	2	Trace	1.35	2.3
2257	Ohio	0	0	0	1	12	1.52	2.0
2267	Wisconsin	0	0	0	Trace	Trace	1.49	2.7
2301	Canada	0	0	0	Trace	0	1.25	2.5
2304	Michigan	0	0	0	Trace	Trace	1.51	2.2
2305	Idaho	0	0	94	Trace	Trace	1.53	2.3
2306	Chile	0	0	43	0	0	1.50	2.3
2307	Bohemia	0	0	45	Trace	2	1.60	2.7
2308	Germany	0	0	50	Trace	—	1.53	2.5
2309	Italy	0	0	85	20	5	1.27	1.7
2310	Chile	0	0	0	Trace	0	1.59	2.4
2311	Minnesota	0	0	0	Trace	Trace	1.40	3.4
2321	France	0	0	—	Trace	—	1.51	—
2334	France	0	0	—	Trace	—	1.62	—
54980	Italy	0	0	6.3	10	8	1.12	2.3
54999	Italy	0	0	85	20	3	.80	2.2
55002	Riga	0	0	—	Trace	Trace	1.27	2.0
56179	Italy	0	0	57	15	4	1.15	2.8
56181	France	0	0	12.5	Trace	0	1.57	2.4
56182	France-Brittany	0	0	17.5	3	4	1.17	2.3
56285	Denmark	0	0	—	Trace	—	1.10	—
56440	Italy	0	0	—	25	—	.76	—
56441	Australia	0	0	—	Trace	—	1.44	—
56616	Italy	0	0	—	15	—	1.22	—
56635	Hungary	0	0	—	Trace	—	1.58	—
56661	Italy	0	0	—	18	—	.98	—
00427	Rosendaal	0	0	—	Trace	—	1.56	—
55502	France	0	0	—	Trace	—	1.52	—
	Wisconsin	0	0	—	Trace	0	1.60	2.6

badly infested with quack grass. On this account, because of the lack of uniformity in the different clover plats, the yield test was rejected as unreliable. Table 5 contains results for Marshfield and Ashland. It will be noted that several more varieties were in the test at the Ashland than at the Marshfield station.

The most noteworthy feature about the 1923 to 1924 test at Ashland and Marshfield was the entire absence of winterkilling. On the other hand, at Ashland the disease factor evidently reduced yields of some strains. This fact appears to hold true for strains No. 2236, 2309, 54999, 56440, and 56661. These are all of Italian origin. Yields of cured hay were much less than of varieties not affected with disease.

THE 1924 TO 1925 EXPERIMENTS

Thirty-six strains of red clover were sown at the Ashland station, 27 at Spooner, and 25 at Marshfield. Data for each test are given in a separate table. (See Tables 6, 7, and 8.)

TABLE 6.—*Winter hardiness and yield tests of red clover, comparing seed of foreign and American origin, Marshfield branch station, 1924 to 1925.*

Variety No.	Source	Winterkilling	Air-dry hay per acre (2nd cutting)
		%	*Tons*
2397	Italy	8	0.47
2399H	France	10	0.63
2399N	France	5	0.41
2399Q	France	6	0.67
2401	France	0	0.92
2399B	Chile	7	0.88
2399M	Chile	7	1.07
2403	Chile	7	1.03
2301	Canada	7	0.74
2404	Canada	4	0.85
2409	Canada	10	1.10
2399E	England	5	0.62
2399F	England	9	0.67
2399J	Transylvania	5	0.73
2399K	England	5	0.73
2399L	Germany	3	0.72
2413	Hungary	8	0.96
2307	Bohemia	0	0.46
2396	Oregon	0	0.39
2399G	Oregon	0	0.41
2405	Oregon	0	0.43
2407	Idaho	0	0.46
2399A	Michigan	0	0.56
2406	Minnesota	9	0.79
2410	Wisconsin	0	0.99

The winter of 1924 to 1925 was very mild and not much winterkilling resulted. Strain No. 2397 winterkilled quite badly. That and strain No. 56661, also of Italian origin, showed a high percentage of disease. It would appear that there is a very close connection between amount of disease and degree of winterkilling. Quite likely, winter injury weakened the plant and rendered it more susceptible to infection. The season of 1924 to 1925 was one of the driest on record. Consequently, acre yields are all very low. At Spooner yields were also affected by lack of moisture, though in a less degree than at Ashland. The percentage of winterkilling was negligible. There was considerable disease noted. However, yields did not seem to be affected to any great extent. There is some indication that Oregon clover seed is not as desirable as that from the north-central states. French seed gave good returns, although considerable disease was noted.

TABLE 7.—*Winter hardiness, disease resistance, and yield tests of red clover, comparing seed of foreign and American origin, Spooner branch station, 1924 to 1925.*

Variety No.	Source	Winter-killing	Disease infection	Drought resistance	Yield per acre
		%	%		*Tons*
2397	Italy	0	35	Good	1.28
2399H	France	0	15	Good	1.90
2399N	France	0	15	Good	1.76
2399Q	France	0	15	Good	2.01
2401	France	5	15	Good	2.01
2399B	Chile	14	15	Good	2.28
2399M	Chile	5	15	Good	1.94
2403	Chile	13	15	Good	1.73
2301	Canada	0	Trace	Good	1.58
2404	Canada	0	Trace	Good	1.90
2409	Canada	0	Trace	Good	1.42
2399E	England	9	Trace	Good	1.56
2399F	England	8	Trace	Good	1.41
2399J	Transylvania	0	Trace	Fair	1.64
2399K	England	0	Trace	Good	1.46
2399L	Germany	4	Trace	Good	1.61
2413	Hungary	7	15	Fair	1.83
2307	Bohemia	0	Trace	Fair	1.37
2396	Oregon	5	Trace	Fair	1.16
2399G	Oregon	4	Trace	Good	1.16
2405	Oregon	0	Trace	Fair	1.29
2407	Idaho	0	Trace	Fair	1.60
2399A	Michigan	8	Trace	Fair	1.47
2406	Minnesota	13	Trace	Fair	1.53
2410	Wisconsin	3	Trace	Fair	1.73
2412	Altaswede	4	Trace	Fair	1.95
55002	Latvia	8	Trace	Good	1.32

No winterkilling took place at Marshfield station. Stands were low because of drought in the fall of 1924. As a result, there was very much weed growth, so much, indeed, that the first cutting was not cut separately, as the data were deemed unreliable. Drought considerably reduced the yields of the second cutting. No disease notes were recorded. There is some indication that Oregon seed is not adapted to Wisconsin conditions.

TABLE 8.—*Winter hardiness, disease resistance, and yield tests of red clover, comparing seed of foreign and American origin, Ashland branch station, 1924 to 1925.*

Variety No.	Source	Winter-killing %	Disease infection %	Drought resistance %	Yield per acre *Tons*
2397	Italy	47	35	Very poor	0.09
2399H	France	10	3	80	0.30
2399N	France	10	1	75	0.33
2399Q	France	10	1	75	0.31
2401	France	10	1	75	0.28
2399B	Chile	21	3	90	0.42
2399M	Chile	21	3	90	0.46
2403	Chile	21	1	90	0.40
2301	Canada	5	1	88	0.45
2404	Canada	3	1	90	0.52
2409	Canada	16	1	90	0.51
2399E	England	21	15	70	0.32
2399F	England	21	2	85	0.44
2399J	Transylvania	13	4	90	0.49
2399K	England	16	1	88	0.46
2399L	Germany	3	1	88	0.51
2413	Hungary	3	1	90	0.49
2307	Bohemia	11	1	90	0.53
2396	Oregon	2	1	88	0.47
2399G	Oregon	11	2	85	0.39
2405	Oregon	16	2	90	0.39
2407	Idaho	11	4	88	0.44
2399A	Michigan	9	1	85	0.37
2406	Minnesota	5	2	88	0.41
2410	Wisconsin	5	1	90	0.42
2412	Atlaswede	10	1	88	0.34
56441	Hungary	5	2	90	0.39
56661	Italy	16	25	70	0.25
56772	Denmark	9	1	90	0.29
56795	New Zealand	16	1	90	0.40
56856	Finland	22	1	90	0.29
57775	Holstein	4	1	90	0.46
57776	Reinland	5	1	90	0.44
57780	Silesia	1	1	90	0.34
04427	Idaho	2	2	88	0.35

Foreign seed, if imported at all, should be purchased on its merits only and the containers should bear the name of the country of origin, with labels showing purity and germination test. Proper certificates of inspection should accompany all shipments.

It is plainly evident that great difficulties exist in getting at the true source of seed even before it reaches American ports of entry. No doubt, a system of shipment in sealed bags can be enforced. The American grower should be protected from unwittingly buying foreign-grown seed. It has been suggested that all imported clover seed be stained before it is released from the custom house.

How to prevent shipping from one foreign country to another and re-exporting to the United States as if the seed had been grown in the country from which shipment is made is not clear to the writer.

Good red clover seed is of such great importance for successful agriculture in the northern states and to Wisconsin in particular that all efforts should be made to insure an adequate supply of reliable, American, northern-grown seed.

GENERAL CONCLUSIONS

A study of the data for the five years and for all the three stations justifies the general statement that foreign clover seed should not be sown in Wisconsin.

At Spooner foreign strains winterkilled badly every season but two. Severe killing occurred at Ashland and at Marshfield two seasons out of five.

A very important count against foreign clover seed is the frequency with which noxious weeds are found. This applies for seed imported from practically all countries on the list.

OBSERVATIONS ON CORN SMUT AT AKRON, COLORADO[1]

F. A. Coffman, W. H. Tisdale, and J. F. Brandon[2]

INTRODUCTION

Observations on corn smut (*Ustilago zeae*) were made during the seven years, 1917 to 1923, inclusive, at the United States Dry-Land Field Station at Akron, Colo., which is operated by the Office of Dry-Land Agriculture Investigations of the Bureau of Plant Industry, U. S. Department of Agriculture. Akron is situated at an elevation of about 4,560 feet in northeastern Colorado in the western portion of the Great Plains area. The 17-year average seasonal (April to September, inclusive) precipitation is 13.68 inches, and the annual precipitation slightly less than 18 inches (3) [3] The experiments were conducted cooperatively by the offices of Cereal Investigations and Dry-Land Agriculture.

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[1] Contribution from cooperative investigations between the Offices of Cereal Investigations and of Dry-Land Agriculture Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication February 23, 1926.

[2] Associate Agronomist in oat investigations, Pathologist in cereal smut investigations, and Superintendent of U. S. Dry-Land Field Station at Akron, Colorado, respectively.

During the four years from 1917 to 1920, inclusive, corn smut was prevalent at the Akron station, but the infection was more severe in some seasons than in others. The percentages of infection seemed to vary inversely with the quantity of seasonal rainfall. Some difference in the quantity of smut in ear-row strains also was noted.

The smut observations were made largely in conjunction with experiments conducted primarily for other purposes than the study of corn smut, and as a result several items of primary importance to the smut study were overlooked. Among such items were location of the infection, time of infection, etc

The smut percentages given are based on the number of the plants actually infected, regardless of the size of the smut galls or of their location on the plants

The corn was not grown in any definite crop rotation system but seldom was grown for two successive years on the same land. The smut infection, no doubt, resulted largely from wind-blown spores. The crop usually was planted between May 20 and 31 and tasseling generally occurred from July 10 to 20. In 1920 and 1921, the corn was planted May 21 In 1922, practically all plantings were made May 26 to 29, and in 1923, during the last two days of May

More than 55,000 corn plants were examined in the four-year period, 1920 to 1923, inclusive Data were obtained on several phases of the smut problem. In several instances these data serve to confirm similar data published by previous writers. The following phases of the problem were studied: (a) The effects of seasonal conditions on infection; (b) varietal susceptibility; (c) differences in the susceptibility of open-pollinated strains within a variety; and (d) differences in the susceptibility of ear-row selections from a common ear-row parentage.

EFFECTS OF SEASONAL CONDITIONS ON INFECTION

Personal observations and a survey of available literature indicate that the greatest losses from corn smut occur in the United States in the semiarid portion of the Great Plains area. Pammel and Stewart

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[3] Reference by number is to "Literature Cited," p. 411.

(9) and Selby and Hickman (12) assert that dry weather is conducive to smut infection. Piemeisel (10) concluded that plants 2 to 3 feet high are most susceptible and notes his results as agreeing with those of Brefeld (2) and of Hitchcock and Norton (6). Piemeisel, contrary to the writers first cited, believed that moist weather is favorable for infection, an opinion shared by Arthur and Stuart (1) and MacMillan (8). Potter and Melchers (11) state that "corn smut * * * is becoming an important limiting factor in corn production in regions of relatively scant rainfall." They also state that "an ecologic study covering four crop seasons has indicated that moisture is not a limiting or controlling factor in the occurrence of corn smut, and that infection does not depend so much on the time of the season as on the stage of development of the host plant."

Tisdale and Johnston (13) have found that corn seedlings are susceptible to smut infection almost as soon as they emerge from the soil. They find that high temperatures (70–90°F.) accompanied by humid conditions favor infection. Actual signs of the disease often are discernible within five days after inoculation when conditions favor infection. This conclusion does not seem to agree with reports from the semiarid area. On the other hand, when it is considered that the corn plant is in a susceptible condition for many days and that only a comparatively few hours are necessary for infection to take place when the conditions are right, it is readily apparent that generalizations based on average seasonal conditions mean very little. Dry weather, no doubt, aids infection most by allowing the overwintered spores to remain dry and ungerminated in the surface soil and by producing conditions which aid wind dissemination of the spores. Spore survival doubtless is influenced by the weather conditions of the entire year.

Data on precipitation and temperatures are presented in Table 1, together with percentages of smut infection in the same years. These data show that in 1921, the year of least precipitation and heaviest infection, the driest part of the season was in May and June, with a fair quantity of rain in July and August. In general, in this section the greater amount of smut infection takes place in July and August. Detailed records of daily precipitation, cloudiness, dew, temperatures, and the dates on which smut appeared on the plants are not available, and without these the exact relation of weather conditions to smut infection cannot be determined.

The data which are available confirm the opinions of others as to the greater prevalence of smut in dry seasons. The writers believe that the dry climatic conditions are indirectly responsible for heavy

TABLE 1.—*Smut-infection percentages and precipitation and temperature records at the U.S. Dry-Land Akron Field Station, Akron, Colo., in each of the four years 1920 to 1923, inclusive.*

	Corn smut			Precipitation in inches			
Year	Number of observations	Total number plants	Percentage smutted	May	June	July	August
1920	147	12,461	11.86	1.78	4.89	4.72	1.45
1921	118	16,754	25.50	0.50	1.06	2.25	1.55
1922	390	17,645	18.54	3.62	1.43	3.24	1.24
1923	63	8,477	4.24	4.94	2.17	3.62	0.75

	Temperature, F.							
Year	May		June		July		August	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1920	54°	42 67°	62°	51-73°	71°	57-86°	67°	53-82°
1921	56°	41-72°	68°	53-82°	74°	59-89°	72°	57-86°
1922	56°	43-69°	69°	54-84°	71°	56-87°	75°	59-91°
1923	54°	43-66°	66°	53-79°	73°	59 87°	69°	55-84°

infection. The dry weather, in addition to preserving the spores in viable condition and making possible their dissemination by the wind, often is accompanied by high temperatures which favor infection. The corn plants are retarded in growth during extremely dry weather. The wind-blown spores lodge in the apical buds and inside the sheaths. As soon as there is sufficient precipitation to keep these parts moist for a few days, infection takes place if the temperatures are sufficiently high. From Table 1 it will be noted that in 1923, when the lowest percentages of smut occurred, there was heavy rainfall during the first three months of the season, whereas August was very dry with fairly low temperatures. These conditions were not conducive to heavy smut infection. In 1921, there was very little precipitation in May and June but considerable rainfall in July and August, together with high temperatures, a combination which favors infection. In 1922, when smut infection was fairly abundant, the rainfall was rather uniformly distributed through the season. The temperatures were above normal in July and very high in August. The abundance of smut in the previous year supplied an abundance of inoculum which probably contributed to the heavy infection.

VARIETAL SUSCEPTIBILITY

Potter and Melchers (11) tested 25 varieties of maize. No variety showed any consistent behavior toward smut infection. The results obtained at the Akron station show some consistent varietal differences relative to the quantity of infection from year to year. In some years the percentages of infection in all varieties were higher than in other years. The lowest percentages of infection consistently occurred in ear-row selections made at Akron in 1919 for the purpose of developing smut-resistant strains. Differences existed among those varieties in which no selection for resistance was made, but they were much less consistent and almost negligible. The varietal data are presented in Table 2.

TABLE 2.—*Annual and 3-year average percentages of smut infection in different corn varieties at Akron, Colo., in the three-year period, 1921–1923, inclusive.*

Variety	Percentages of infection			
	1921	1922	1923	Mean all years
Akron White	37.8	9.8	4.0	17.2
Disco Ninety-day	28.6	9.4	6.2	14.7
Silver King	23.8	11.6	4.2	13.2
Swadley	27.7	14.6	3.2	15.2
Swadley Strain A$_{10}$	11.1	6.7	2.1	6.6
Swadley Strain A$_{22}$	20.7	4.3	1.2	8.7
Akron Yellow	39.7	17.4	2.9	20.0
Fulton	40.9	11.5	5.9	19.4
Minnesota No. 13	30.0	15.3	8.6	18.0
Claridge (U. S. Sel. 125)	30.8	16.1	[a]	23.5
Northwestern	[a]	23.9	5.8	14.9
White Cap	[a]	9.3	3.7	6.5

[a] Variety not grown.

DIFFERENCES IN SUSCEPTIBILITY OF OPEN-POLLINATED STRAINS WITHIN A VARIETY

That selfed strains of corn within a variety differ in degree of susceptibility to smut has been demonstrated by Jones (7), Hayes, Stakman, Griffee, and Christensen (5), Garber and Quisenberry (4), Tisdale and Johnston (13), and others. These investigators agree that smut-resistant and smut-susceptible, self-fertilized strains may be isolated. Open-pollinated, ear-row strains at Akron also showed differences in quantity of smut infection. Table 3 presents data from 30 ear-row strains of the Swadley variety. Selections Nos. 1 to 7, inclusive, originated as ear-rows in 1919. The ears were taken from ear-rows grown in 1918. Selections Nos. 8 to 20, inclusive, originated as ear-rows in 1920 from ears from similar rows in 1919, and Nos. 21 to 30, inclusive, as ear-rows in 1921 from ears taken from the rows grown in 1920. In all cases ear-row selection was practiced for two seasons. At the end of the second season the ears from each ear-row were shelled together or bulked and mass selection within each strain followed thereafter. The Swadley variety is rather nondescript, usually having white-capped yellow kernels varying from a dent to almost a true flint in type. A few strains of this variety consistently produced low percentages of smut, while other strains were extremely variable in their susceptibility from year to year.

In 1923, only the selections A-10, A-22, and check were grown. The percentages of infection in 1923 were 2.1, 1.2, and 3.2, and the four-year averages of the selections were 5.7%, 8.4%, and 13.8%, respectively

All strains showing unusual susceptibility to smut were discontinued after one or two years on account of their lack of economic value and shortage of space. For this reason the spread in percentages of infection shown by the different strains probably is not as great as it otherwise would be. The data, however, indicate that differences in smut resistance exist in open-pollinated strains of corn.

TABLE 3.—*Annual and three-year average percentages of smut infection in different strains of Swadley corn, originally selected by ear-row methods.*

Number of selection	Strain	Percentages of infection			
		1920	1921	1922	Mean, 1920-1922
1	P-4	6.6	32.7	[a]	—
2	P-7	5.0	19.9	18.5	14.5
3	P-8	5.0	21.3	[a]	—
4	P-10	6.3	14.9	8.1	9.8
5	P-11	6.0	14.7	0.0	6.9
6	P-16	3.2	34.3	[a]	—
7	P-17	6.7	41.3	[a]	—
8	A-6	9.5	18.7	9.5	12.6
9	A-7	3.1	20.3	5.9	9.8
10	A-10	2.7	11.1	6.7	6.8
11	A-20	7.7	13.1	13.8	11.5
12	A-21-a	2.7	17.7	28.6	16.3
13	A-22	7.5	20.7	4.3	10.8
14	B-6	10.5	18.9	28.6	19.3
15	B-10	10.4	28.4	[a]	—
16	B-12	8.2	19.3	[a]	—
17	B-13	17.7	25.6	[a]	—
18	B-16	20.5	18.9	11.9	17.1
19	B-22	6.8	23.0	[a]	—
20	B-31	5.2	18.8	15.8	13.3
21	A-1	6.4	24.1	4.8	11.8
22	A-3	5.7	26.1	3.3	11.7
23	A-17	7.1	19.3	5.9	10.8
24	A-21-b	7.1	51.4	12.0	23.5
25	A-28	11.5	48.8	23.3	27.5
26	A-32	9.6	41.2	14.6	21.8
27	B-1	9.5	22.1	4.7	12.1
28	B-2	7.2	16.1	21.1	14.8
29	B-4	6.2	20.0	3.5	9.9
30	B-7	3.0	9.1	5.1	5.7
	Check	8.7	28.0	14.6	17.1

[a] Not grown in 1922.

TABLE 4.—*Percentages of smut in parent and progeny ear-rows of four varieties of corn grown at Akron, Colo.*

	First year[a]	Second year			
Variety and strain number	Percentage of infection in parent ear-row	Number progeny ear-rows	Mean infection all progeny rows[b]	Range of infection progeny rows Low	High
Disco Ninety-day	28.6	—	9.4	9.4	9.4
Selection No. 2	18.8	6	6.9	3.2	10.0
Selection No. 4	29.8	2	13.2	10.0	16.3
Selection No. 6	20.8	2	4.9	2.3	7.4
Selection No. 7	22.9	4	15.4	12.3	19.3
Selection No. 3	22.7	1	16.2	16.2	16.2
Silver King	23.8	—	11.6	11.6	11.6
Selection No. 3	12.6	4	18.9	13.9	30.1
Selection No. 6	11.2	4	13.5	10.1	16.7
Selection No. 7	13.8	4	15.8	10.1	19.2
Selection No. 8	15.6	6	14.1	8.1	22.6
Selection No. 9	18.6	2	15.2	14.4	16.0
Akron Yellow	39.7	—	17.4	17.4	17.4
Selection No. 2	23.5	12	8.0	1.1	15.7
Selection No. 3	26.9	2	4.5	4.2	4.7
Selection No. 4	27.3	2	3.3	3.2	3.4
Selection No. 7	14.4	3	12.5	6.7	22.8
Selection No. 9	46.8	1	12.7	12.7	12.7
Swadley[c]	—	—	14.8	14.8	14.8
Selection B-2	—	7	9.9	8.0	13.8
Selection B-5	—	9	11.7	4.1	20.6
Selection B-8	—	7	18.4	7.3	44.3
Selection B-9	—	6	25.9	19.2	32.1
Selection B-10	—	10	20.8	10.5	38.1
Selection C-14	—	4	8.8	3.1	12.1
Selection C-21	—	5	9.9	2.7	19.5
Selection C-22	—	6	13.2	8.2	18.2
Selection C-23	—	6	12.8	2.7	26.0
Selection C-25	—	6	11.4	6.8	15.5

[a] The first year for the first three varieties was 1921; for Swadley, 1919.

[b] Mean infection of five additional Disco Ninety-Day selections in 1921 was 27.7%; of five additional Silver King selections, 20.6%; and of five Akron Yellow selections, 22.0%. No progeny rows of these selections were grown in 1922.

[c] Mean of all selections grown, no data obtained on selections in 1919 or on original variety in 1920. The data presented for the other three varieties were from plats not adjacent to the selection plats.

SMUT SUSCEPTIBILITY OF EAR-ROW SELECTIONS FROM THE SAME PARENT EAR-ROW

Some of the ear-row selections showed lower percentages of infection than others. The source of ears planted in the various ear-rows was traced in order to determine the amount of infection in different selections from the same source. Ears from 25 strains from 4 varieties were studied. As in the previously described experiment, all strains were dropped from the experiment as soon as they proved to be unusually susceptible to smut. The range of strain differences in susceptibility would have been greater, no doubt, had all the strains been retained.

The data which are given in Table 4 show that in some cases sister strains behaved differently toward smut infection, while sister strains from other parent ear-rows reacted very similarly, all showing either high or low percentages of smut. It will be noted that strains of Silver King varied less in the percentages of smut infection than those from the other varieties grown. The Silver King variety as grown in these experiments also was less variable for character of plant and ear than were the others. The same differences do not seem to exist in all cases between the progeny of the parent ear-rows as existed between the parent ear-rows themselves. As the smut percentages are comparatively low in all strains it is probable that this lack of correlation was due to some extent to chance escape from infection.

SUMMARY

During the period 1920 to 1923, inclusive, data were obtained on some of the factors influencing the infection of corn by smut (*Ustilago zeae*) at the United States Dry-Land Field Station, Akron, Colo.

The percentages of smut were found to vary in different seasons. Scant precipitation in May and June followed by moderate rainfall and comparatively high temperatures seemed to favor the disease. Such conditions prevailed in 1921. Moderate amounts of precipitation throughout the season accompanied by high temperatures in July and August (1922) seemed to favor moderately abundant infection. Such a result was obtained in 1922. A rather heavy precipitation in the early part of the season followed by scant rainfall and low temperatures in the later summer was not conducive to heavy infection. The greater part of the smut appeared in July and August in all years.

Varietal differences in susceptibility of corn to smut were found. Strains selected for smut resistance consistently showed lower percentages of smut.

Strains of Swadley corn grown during 1920 to 1922, inclusive, showed marked differences in degree of smut susceptibility. Although variation from year to year occurred in a given strain, some strains produced consistently less smut than others.

Ear-row progenies from the same parent ear-row in some cases showed marked differences in degree of smut susceptibility, while in other cases they were very similar, all strains showing either high or low percentages of smut. This may prove of some practical value in breeding smut-resistant strains of corn.

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THE NODULE ORGANISM OF THE COWPEA GROUP[1]

THOMAS E. RICHMOND[2]

The work of Löhnis and Hansen[3] and of Shunk[4] has established beyond doubt that the nodule organisms of the Leguminosae are to be divided into two groups, as follows: First, legumes of European origin are inoculated by *Bacillus radicicola* which is of peritrichous flagellation; and second, legumes of Asiatic origin are inoculated by *Pseudomonas radicicola* which is of monotrichous flagellation.

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Through the courtesy of the United States Department of Agriculture the seeds of a large number of eastern legumes were obtained and tested out as to their ability to cross-inoculate with the cowpea organism.

The methods used in the greenhouse trials and the results obtained are outlined below.

PROCEDURE

PREPARATION OF SAND AND CONTAINERS

The sand used was a white quartz sand and, as purchased, was, as a rule, free from the nodule organism, but in order to be sure that one source of chance inoculation had been eliminated it was sterilized in the hot air oven. When working with cross-inoculation studies, or in proving out stock cultures, pint Mason jars have been found to be very satisfactory containers, but if nitrogen assimilation is to be studied 1-gallon earthen jars should be used. After the sand had been sterilized in the proper container, a little calcium carbonate was worked into the surface of each jar. After the optimum moisture content had been established, the jars were ready for planting.

STERILIZATION OF SEEDS

The seeds to be used were sterilized before planting. Mercuric chlorid, 60% alcohol, or 10% chloramine T may be used with satisfactory results, but the mercuric chlorid solution method of sterilization was used in most cases. The seeds were placed in a suction flask and enough warm mercuric chlorid solution added to cover them and suction from a water pump applied for 3 minutes. The seeds were washed with at least six changes of distilled water, and spread out to dry. The mercuric chlorid solution used was made by placing 2.5 cc. of a 40% mercuric chlorid solution in commercial hydrochloric acid and diluting to 1,000 cc.

PLANTING AND INOCULATION OF SEEDS

The seeds to be planted were worked down into the wet sand with a pair of forceps, care being taken to place the hylum downward. The culture to be tested was shaken up with distilled water and poured over the seeds, and a thin layer of dry sand added.

TREATMENT AFTER GERMINATION

Little trouble is encountered with seedlings of the pea type in which the cotyledons remain under the surface of the sand, and the plumule is pushed to the surface by the elongation of the stem of the epicotyl; but in the case of seedlings of the bean type in which the cotyledons are pulled out of the sand by the hypocotyl, it is sometimes necessary to aid the cotyledons in casting off the seed coat. This should be done with sterile forceps, as it is very easy to carry inoculation from one jar to another if this operation is performed with the fingers. In seedlings of the bean type, the cotyledons should be cut off as soon as the plumule is free. If this is not done, the plant food stored in the cotyledons will greatly retard nodule formation and nitrogen assimilation. Tap water was used as the nutrient solution and was found to be free of the legume organism. With good growing weather, the plants should be ready for examination four weeks after germination, but if the plants are grown in cloudy weather or during the winter, artificial light should be used.

CHANCE INOCULATION

The jars should be protected from the casual observer who has a habit of poking a finger into different jars to estimate the moisture content. If reasonable care is taken very little chance inoculation should take place. It has been found, for example, that if one inoculated seed and four sterile seeds are planted and grown in the same pint jars when the plants are examined at the end of a month's growth only one plant, as a rule, will be found to be inoculated. This would indicate that there is little movement of the legume organism away from the inoculated seed.

EXAMINATION OF ROOTS FOR NODULES

When the plants were ready to examine for nodule formation, the sand was easily washed out of the jars with tap water and the results observed. If pure cultures from any of the nodules obtained are wanted, a very quick and easy way to obtain them is by use of the paraffin block method, as follows: Place a nodule upon a block of paraffin and by means of a hot glass rod imbed it in melted paraffin. When the paraffin has hardened, slice the nodule in two with a sharp knife, touch the center of the mass with the point of the needle, and transfer the culture to a mannite agar slant.

RESULTS

As a result of greenhouse tests it was found that nodules were produced upon the following legumes by the cowpea nodule organism: *Phaseolus angularis* (adzuki bean), *P. aconitifolius* (moth bean), *P. aureus* (mung bean), *P. calcearatus* (rice bean), *P. mungo* (urd bean), *P. cutifolius*, *P. radiatus*, *Vigna sesquipedelis* (asparagus bean), *Cyamopsis tetagonoloba* (guar bean), *Canavalia ensiformis* (jach bean), *Dolichos lablab* (hyacinth bean), *D. biflorus* (kulthi bean), *Crotalaria retusa*, Cherkee clover, and *Cajanus indicus* (pigeon pea).

Pure cultures were obtained from the nodules on each of the above legumes and crossed back upon the cowpea with the formation of nodules in each case.

The results obtained are in agreement with the work of Löhnis and Hansen which placed Asiatic legumes in a group inoculated by *Pseudomonas radicicola*.

LONGEVITY OF THE LEGUME NODULE ORGANISM[1]

Thomas E. Richmond[2]

The question of the viability of the nodule organism has been studied by several investigators with variable results. Fellows[3] inoculated soybean seed with an infusion of the nodule organism and found that the seeds contained viable organisms for six months. Albrecht[4] has shown that dried soils gradually lose their power to cause nodule production so that at the end of six years no nodules were produced by using the dried soil as a source of inoculation. The Wisconsin Experiment Station[5] reports that soybeans were inoculated from the organisms surviving in an acid soil for 17 years. This last is a very interesting case and would indicate that the life of the nodule organism in a soil *in situ* is much longer than that in the same soil dried. Buffer action of soil organic matter must play the rôle of a protective agency against the harmful effects of soil acidity.

EXPERIMENTAL

A series of 11 soil samples from 7 Illinois soil experiment fields were obtained in 1919 and 1920 and examined as to their power to cause nodule formation upon the roots of soybeans and cowpeas. Although soybeans had not been grown upon some of these fields for from six to eight years and although the soils were of various degrees of acidity, nodules were produced in all cases.

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[1] Contribution from the Department of Agronomy, University of Illinois, Urbana, Ill. Received for publication February 27, 1926.

[2] Formerly Associate in Soil Biology; now Instructor in Soils, Ohio State University, Columbus, O.

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These soils were then stored in sealed Mason jars in the laboratory until the spring of 1924, at which time they were re-examined as shown in Table 1.

An examination of the results shows that when soils with a lime requirement of 3 tons of limestone per acre were stored for 3½ years the nodule organism of both the soybean and cowpea had been killed. With soils of a lime requirement of from 3,000 to 4,000 pounds per acre, the soybean nodule organism had been killed, but the cowpea organism still survived. With those soils with a lime requirement of less than 1 ton per acre, both the soybean and cowpea nodule organism survived.

TABLE 1.—*Results of different soil treatments upon the longevity of the legume nodule organism.*

Field	Plat	Treatment[a]	KSCN	Hopkins	Jones	pH	Inoculation Soy-bean	Inoculation Cow-pea
Raleigh	210	None	Deep red	1,975	6,107	4.5	—	—
Ewing . . .	110	None	Deep red	500	6,860	4.6	—	—
Minonk......	401	None	Deep red	700	6,750	4.8	—	—
Ewing . .	108	RLP	Red	160	3,086	4.9	—	+
Virginia.....	101	None	Red	133	4,078	4.7	—	+
Newton	408	RLP	Red	250	3,090	5.4	—	+
Raleigh.......	208	RLP	Clear	100	643	7.2	+	+
Virginia	108	RLPK	Faint	68	1,607	5.8	+	+
Minonk......	408	RLP	Faint	300	2,140	5.8	+	+
Toledo.......	104	MLP	Faint	25	1,605	6.3	+	+
Oblong .. .	408	RLP	Faint	200	2,750	5.8	+	+

[a] R = Residues. L = Limestone. P = Rock phosphate. K = Potassium.

The soil type as such appears to make little difference in the results, as both rich and poor soils are found in each group, Raleigh, Ewing, Newton, Toledo, and Oblong all being of the poor gray or yellow gray silt loam on tight clay type, while the sample from the Virginia field is a brown silt loam (Muscatine) and that from the Mononk field is a black clay loam (Clyde).

The residual effects of the different treatments appear to be the controlling factor.

MUDDY WATER METHOD OF INOCULATION

The method of inoculation most commonly employed by farmers is the muddy water method. In this method soil from a field which has grown the crop in question is mixed with water and slopped over the seeds. The seeds are worked over until each has a thin layer of mud upon its seed-coat. They are then allowed to dry and are stored until conditions are possible for planting.

As it has long been recognized that soybeans, as well as other seeds, inoculated by this method sometimes give variable results in nodule formation, two lots of soybeans were inoculated by this method, in one case a neutral soil being used, while in the second case an acid soil with a hydrogen-ion concentration of pH 5.0 was employed.

Seeds from each lot were planted at frequent intervals, and as a result, it was found that the seeds inoculated with the muddy water made from the acid soil were free of nodule-forming bacteria within seven days. The seeds inoculated by muddy water made from the neutral soil retained viable organisms upon their seed coats for almost one year.

SUMMARY

1. The legume nodule organisms are able to survive for many years in an acid soil *in situ*, but are quickly killed upon the soil's being air dried.

2. The legume nodule organisms of the soybean and cowpea were killed by a three-year storage of a soil with a 6,000-pound lime requirement.

3. The soybean organism was killed by three years' storage of a soil with a 3,000- to 4,000-pound lime requirement, but the cowpea organism survived.

4. Both the soybean and cowpea organisms survived three years' storage in soils having a lime requirement of 1 ton or less.

5. Seeds inoculated by the muddy water method where an acid soil is used retain viable organisms for only a very few days.

6. Seeds inoculated by the muddy water method where a neutral soil is used retain viable organisms for almost a year.

A NEW METHOD OF JUDGING WHEAT AT GRAIN SHOWS[1]

W. O. WHITCOMB[2]

The judging of grain and other agricultural products has been one of the important and difficult tasks in connection with county and state fairs for a number of years. Of even greater importance has been the placing of the large number of entries at the International Grain and Hay Show in Chicago each year. The object of this judging and placing of these various products is purely educational.

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[1] Contribution from the Grain Inspection Laboratory, Montana Agricultural Experiment Station, Bozeman, Mont. Published with the approval of the Director. Received for publication February 23, 1926.

[2] Superintendent.

Fairs and grain shows are maintained for the purpose of showing the people what can be produced in a certain community, state, or nation. The supremacy in this contest in production can be decided only by the proper placing of the exhibits.

THE PROBLEM

The standard by which exhibits are judged is dependent upon the purpose for which the product is intended. It is far easier to decide upon this standard in a general way than it is to apply it uniformly for all products or at all agricultural shows. As might be expected, there have been many changes in the details in judging different products. Corn is a good example of this. At one time ear corn was judged for certain fancy points and the prize ear often brought a big price because it was considered of superior quality for seed. It was later discovered by comparative tests that the fancy points had nothing to do with the breeding quality of the corn. It was then that a closer study was made and a different basis of judging corn was adopted. Ear corn is now judged not on fancy points that are pleasing to the eye but on points which show good breeding for the variety or type and adaptability to the region in which it is grown. Another good example is the seed show where various samples of seeds are competing for supremacy as to quality in the matter of pure seed. Again appearance is very deceiving. This led to the establishment in some localities of the "utility seed show." In these utility seed shows the samples are placed according to purity and germination tests which have been made in a seed testing laboratory before the show opens. In this way it is definitely known just what each sample of seed will do.

Wheat is commonly judged at grain shows from the standpoint of its value as a milling wheat. Every fair in the wheat growing sections has a large number of entries of wheat. Many of these are carefully selected and much time has been spent in hand picking to a basis of practically perfect kernels The small size of the exhibits, usually four quarts, permits of a careful examination of each kernel. If this wheat is to be judged from the standpoint of test weight per bushel and appearance, as is commonly done, it is clear that the "best picker" is sure to win. In reality this method of judging does not always award the prize to the best milling wheat. It seems only fair that the method of judging wheat should be changed as the judging of corn and seed in seed shows has been so as to determine the real quality.

MONTANA PLAN OF JUDGING WHEAT

In the fall of 1923 the Montana State Fair offered special prizes for grand sweepstakes special best bushel of Marquis wheat. The premium list stated "Judged from the standard of milling values on the basis of quantity and quality of gluten, flour yield, and other factors that fix actual commercial value Exhibits are to be judged by a committee of Montana millers."

Twenty-one bushel samples of wheat were entered for these prizes and the committee of millers looked them over. They finally decided that it would be impossible for them to judge the wheat without having some tests made. The result was that the 21 samples of wheat were sent to the Montana Grain Inspection Laboratory with instructions to make such tests as would best show the quality of the wheat. The wheat was taken to the experimental milling and baking laboratory and various tests were made. It was finally decided that the following score card would best reflect the composite quality or value of the wheat

Score Card for Judging Quality of Wheat	Points allowed
Purity	10
Test weight per bushel	10
Grade (Federal standards)	15
Dry gluten %	10
Quality of washed gluten	5
Protein %	10
Absorption %	5
Loaf volume	15
Color of bread	10
Texture of bread	10
	100

A study of this score card shows that there are a number of points which apparently interlock. However, it is believed that it is desirable to have the various tests to insure a thorough analysis of the quality of the wheat. Both purity and test weight per bushel are a part of the grade, yet it is desirable that they also be given separate values in order to allow of a closer analysis than the grade requires. The flour yield is omitted because in the experimental milling it is desirable to mill to a scale according to the test weight so as to insure a more uniform flour The grade is given 15 points in the score card because it takes into consideration a number of factors such as color, texture, moisture, foreign material, odor, damaged kernels, and smut. It is important to have both dry gluten and protein content given as they tend to check each other and emphasize the quantity of gluten. The quality of gluten is reflected under three headings in the score card, namely: Quality of washed gluten, loaf volume, and texture of bread. Loaf volume is given 15 points because it is considered the one best expression we have of quality in wheat. Absorption, or the amount of water taken up by the flour in making the dough, is usually associated directly with protein content. However, certain forms of damaged kernels tend to increase the absorption abnormally. Color in bread is a rather intangible factor which can not always be accounted for in the ordinary experimental tests where flour bleachers are not employed.

APPLICATION OF THE SCORE CARD

It was found necessary to adopt a scale of points in applying the various factors in the score card to the results of the tests made. In other words, the upper and lower limits of the various tests had to be established. The following scale of points, while only suggestive, has been found to be fairly satisfactory:

Purity 10 points	
100.0%	10.0
99.5%	9.5
99.0%	9.0
98.5%	8.5
98.0%	8.0
97.5%	7.5
97.0%	6.5
96.5%	5.5
96.0%	4.5
95.5%	3.5
95.0%	2.5
94.5%	1.5
94.0%	0.5

Test weight 10 points	
63.0 lbs	10.0
62.5 lbs	9.5
62.0 lbs	9.0
61.5 lbs	8.5
61.0 lbs	8.0
60.5 lbs	7.5
60.0 lbs	6.5
59.5 lbs	5.5
59.0 lbs	4.5
58.5 lbs	3.5
58.0 lbs	2.5
57.0 lbs	1.0

It will be noted in the scale of points allowed for the various tests that the upper limit is rather arbitrarily set in certain cases. In the cases of purity of wheat and color and texture of bread, where the tests are scored on the percentage scale with 100 as the basis, it is easy to apply the scale of points, but in the other tests it is more difficult. In test weight per bushel 10 points are allowed for 63 pounds or more per bushel. Some wheat may test heavier than this, but it is not frequent. The numerical grade, together with the percentage of dark, hard, and vitreous kernels, is a good basis on which to apply the scale of points, but it is necessary to take other grading factors into consideration. In both dry gluten and protein content 15% is taken as the upper limit, that is, only 10 points are allowed for 15% gluten or protein or anything above it. The quality of the

Grade 15 points

	D H V kernels	
No 1 Hard spring	100%	15 0
	95%	14 5
	90%	14 0
	85%	13 5
No 1 Dark northern spring	80%	13 0
	75%	12 5
No 2 Dark northern spring	80%	11 0
	75%	10 0
No 1 Northern spring	70%	9 0
	60%	7 0
	50%	5 0
No 2 Northern spring	70%	4 0
	60%	3 0
	50%	2 0

Dry gluten 10 points

15%	10 0
14%	9 5
13%	9 0
12%	7 0
11%	5 0
10%	3 0
9%	1 0

Quality of gluten 5 points

Very good	5 0
Good	4 0
Medium	3 0
Poor	0 0

Protein 10 points

15%	10 0
14%	9 5
13%	9 0
12%	7 0
11%	5 0
10%	3 0
9%	1 0

Absorption 5 points

60%	5 0
59%	5 0
58%	4 5
57%	4 0
56%	3 0

Loaf volume 15 points

2,300 cc	15 0
2,200 cc	14 5
2,100 cc	14 0
2,000 cc	13 0
1,900 cc	11 0
1,800 cc	8 0
1,700 cc	4 0
1,600 cc	2 0

Color of bread 10 points

100%	10 0
98%	9 5
96%	9 0
94%	8 5
92%	7 0
90%	5 0
88%	3 0
86%	1 0

Texture of bread 10 points

100%	10 0
98%	9 5
96%	9 0
94%	8 5
92%	7 0
90%	5 0
88%	3 0

gluten or protein above this percentage is not considered equal to that in the lower percentages. Sixty per cent is taken as the upper figure in absorption because it is seldom that good quality flour that has not been permitted to dry out before baking will require more than 60% water to make a good dough. It is considered that 2,300 cc. is a satisfactory test loaf in experimental baking. A larger loaf has no advantage.

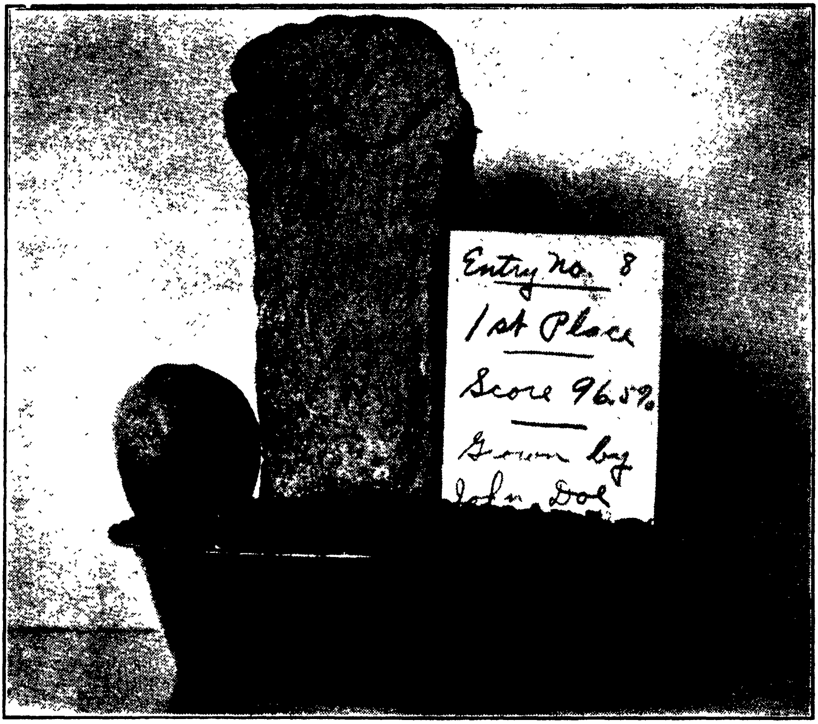

FIG. 1.—A sample of wheat with a gluten puff and a loaf of bread made from it. Each sample of wheat entered for grand sweep stakes special is exhibited in this manner at the grain show. It makes a very attractive display which has an educational value.

USE OF THE SCORE CARD ILLUSTRATED

The application of the score card and the scale of points allowed are best illustrated by scoring a sample ranking high and one ranking rather low. For this purpose the sample of wheat which won first place and the one which won sixth place at the Montana State Fair in 1924 are shown in Table 1.

THE EXHIBIT

In preparing the loaves of bread for exhibit it is necessary to cover them with a water-proofing material to prevent them from drying out. This is accomplished by cutting the loaves in half and dipping them in hot paraffin. Fig. 1 shows an exhibit of a single loaf of bread, together with a gluten puff and a pan of wheat. Fig. 2 is a photograph of the six winning loaves at the Montana State Fair in 1924.

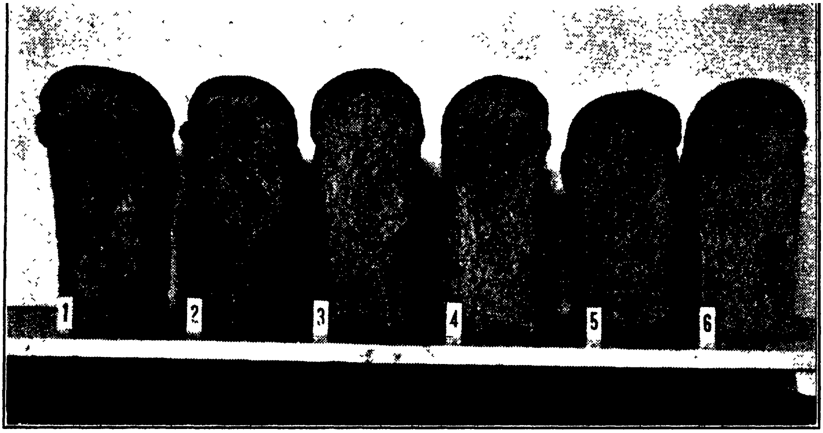

FIG. 2.—Loaves of bread from the six winning samples of wheat at Montana State Fair in 1924. These wheats scored as follows: 1st place, 98.5; 2nd place, 96.0; 3rd place, 95.0; 4th place, 94.0; 5th place, 92.5; and 6th place, 91.5.

TABLE 1.—*The use of the score card and scale of points allowed.*

Test	Perfect score	Sample winning 1st place Test	Score	Sample winning 6th place Test	Score
Purity	10	99.8%	10.0	97.8%	8.0
Test weight per bushel	10	63.0 pounds	10.0	63.0 pounds	10.0
Grade	15	1 hard spring D. H. V. 99%	15.0	1 hard spring D. H. V. 95%	14.5
Dry gluten	10	15.9%	10.0	14.1%	9.5
Quality of washed gluten	5	Good	4.0	Medium	3.0
Protein	10	15.19%	10.0	14.14%	9.5
Absorption	5	59%	5.0	58%	4.5
Loaf volume	15	2,280 cc.	15.0	2,110 cc.	14.0
Color of bread	10	98%	9.5	96%	9.0
Texture of bread	10	100%	10.0	98%	9.5
Totals	100		98.5		91.5

RESULTS

This method of judging wheat has been used for the past three years at the Montana State Fair and for one year each at the Midland Empire Fair at Billings and the Gallatin County Fair at Bozeman. The number of entries for the best bushel of Marquis wheat has ranged from 8 to 26. It has been found desirable to restrict these entries to bushel samples to eliminate hand-picking of the samples as much as possible. If the entries close one week before the fair opens it allows sufficient time to make all the tests on the samples and have the bread and gluten puffs on exhibit when the fair opens.

The interest which has been shown in the exhibits of the bread, together with the samples of wheat, has demonstrated that work of this kind has an educational value. This interest will become more pronounced as the public learns more about quality in wheat through the marketing of their wheat on the protein basis.

HYBRID VIGOR IN RICE[1]

Jenkin W. Jones[2]

Increased vegetative vigor of F_1 hybrids when compared with their parents was observed and commented upon by the earliest plant breeders. Koelreuter noted hybrid vigor in 1761 in reporting upon artificial crosses, hybrid vigor since being reported by breeders as occurring in many species of plants. No data, however, as far as the writer can find, have been reported for rice. Authentic records show that rice has been cultivated extensively in Asia since at least 2500 B. C., in Italy since 1468 A. D., and in the United States since 1694. On the other hand, the earliest record of artificial crossing of rice, so far found, dates only to 1900. It is true, of course, that the records of rice improvement in India and China, where this crop has been grown for centuries, are largely unavailable in any western language.

There are many rice varieties and some of these are no doubt the result of natural crossing, for in more recent years several investigators have observed some natural crossing in rice. The extent of natural crossing appears to depend upon the particular variety under observation and the climatic conditions under which it is grown. The floral organs of rice are extremely sensitive to manipulation and the crop is not easily crossed. The conditions under which rice is grown—submerged land, high humidity, high temperatures, bright sunlight, etc.—also contribute toward making crossed seed more difficult to obtain. Possibly for these reasons few rice hybrids have been artificially produced.

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[1] Contribution from the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture. Received for publication March 3, 1926.

[2] Associate Agronomist and Superintendent of the Biggs Rice Field Station, Biggs, Calif.

MATERIALS AND METHODS

In this paper data are presented on the vigor of F_1 rice plants as compared with their parents. The crosses were made by the writer in the fall of 1923 at the Biggs Rice Field Station, Biggs, Calif. Four pure line rice varieties were used in the crosses reported. The pollen used was collected at random from the male parent rows. One panicle of each female plant was saved and the seed used in this study for comparison with the hybrid plants.

The hybrid and parent seeds were sown on May 9, 1924, in small, square, tarred paper pots which had been previously filled with a sandy loam soil. After seeding, the soil in the pots was saturated with water and was kept moist thereafter until the seedlings emerged, from May 18 to 21. The plants made poor growth in the paper pots and were not very vigorous when transplanted to the nursery on May 28. The plants were spaced 1 foot apart in rows 3 feet apart. This gave each plant more than ample room for normal development, a few plants failing to mature as well as if they had had less space.

When the plants were mature the number of culms per plant was counted, the height of the plant from the surface of the ground to the tip of the most distant spikelet was measured, and the panicles of each plant were harvested separately and placed in large manila envelopes. The envelopes containing individual plant panicles were stored in the office for about two months before the length of the panicles and the weight of the hand-threshed paddy were determined.

EXPERIMENTAL

In this study hybrid vigor is measured in terms of average height of plant, average length of panicle in centimeters, average number of culms per plant, and average yield in grams per plant.

HEIGHT OF PLANTS

In Table 1 is shown the average height, in centimeters, of F_1 plants in comparison with the parental plants. The parental plant yields include the yields of the female parent of each cross. As the male parents were also used as female parents in certain crosses, the yields for the female parents are thus used in the male parent column. This is believed to be fair since all varieties used in these crosses are pure line selections, the records of which are definitely known. The number of parent and hybrid plants used in this study are too few to warrant the drawing of definite conclusions. The results, however, are no doubt indicative of what would be expected with larger numbers of plants grown under like conditions.

As shown in Table 1 the F_1 plants of each cross were taller than either parent. The smallest average increase in height for the F_1 plants over the average of the parental plants was for the cross Butte x Colusa, and the largest average increase was for the cross Eureka x Caloro. The average percentage increase in height of F_1 plants over the parental plants for the four crosses was 8.98. These results, while based on data from few plants, indicate that there is hybrid vigor with respect to height of plants.

LENGTH OF PANICLES

Table 2 shows the average length of panicle for the F_1 plants in comparison with the parental plants for the same crosses. In three of the four crosses the average length of panicle for the F_1 plants was greater than the average of the parental plants. In the cross Eureka x Caloro the average length of panicle for the F_1 plant was less than the average of the parental plants. The average percentage increase in length of panicle for the F_1 plants over the parental plants for the four crosses was 2.12. This increase is evidently not significant.

NUMBER OF CULMS PER PLANT

The data regarding the number of culms of the F_1 and parental plants for the four crosses are presented in Table 3. In each cross the F_1 plants produced more culms than the parental plants. The average increase in number of culms of the F_1 plants over the parental plants varied from 3.1 for the cross Eureka x Caloro to 6.7 for the cross Butte x Caloro, or a percentage increase of 34.83 to 94.37, respectively. The average percentage increase in number of culms for the F_1 plants over the parental plants for the four crosses was 67.60.

With respect to number of culms per plant, it appears evident that for all crosses hybrid vigor was exhibited by the F_1 plants.

YIELD PER PLANT IN GRAMS

Probably the best indicator of hybrid vigor is the yield per plant. In Table 4 is shown the average yield of the F_1 and parental plants for the crosses under consideration. The average increase in yield for the F_1 plants over the parental plants ranged from 11.3 to 20.4 grams for the crosses Colusa x Caloro and Butte x Colusa, respectively. The average percentage increase in yield for the F_1 plants over the parental plants for the four crosses was 110.13.

TABLE 1.—*Average height, in centimeters, of F_1 plants in comparison with the parental plants, at Biggs, California, in 1924.*

Female parent	Number of plants	Average height of plant	Male parent	Number of plants	Average height of plant	Average height of parents	Cross		Increase of hybrids over parents	
							Number of plants	Average height of plant	Height	Percentage
Caloro	5	82.4	Colusa	5	93.4	87.9	4	96.5	8.6	9.78
Butte	5	87.4	Colusa	5	93.4	90.4	6	96.3	5.9	6.53
Eureka	4	89.8	Caloro	5	82.4	86.1	1	97.0	10.9	12.66
Colusa	5	93.4	Caloro	5	82.4	87.9	1	94.0	6.1	6.94
Average										8.98

TABLE 2.—*Average length of panicle, in centimeters, of F_1 plants in comparison with the parental plants, at Biggs, California, in 1924*

Female parent	Number of plants	Average length of panicle	Male parent	Number of plants	Average length of panicle	Average length of parental panicles	Cross		Average increase of hybrids over parents	
							Number of plants	Average length of panicle	Length of panicle	Percentage
Caloro	5	16.4	Colusa	5	16.8	16.6	4	17.5	0.9	5.42
Butte	5	16.8	Colusa	5	16.8	16.8	6	16.9	0.1	0.60
Eureka	4	18.2	Caloro	5	16.4	17.3	1	17.1	0.2	−1.16
Colusa	5	16.8	Caloro	5	16.4	16.6	1	17.2	0.6	3.61
Average										2.12

TABLE 3.—*Average number of culms of F_1 plants in comparison with the parental plants, at Biggs, California, in 1924.*

Female parent	Number of plants	Average number of culms	Male parent	Number of plants	Average number of culms	Average number of culms of parents	Cross		Increase of hybrids over parents	
							Number of plants	Average number of culms per plant	Number of culms	Percentage
Caloro..........	5	7.8	Colusa	5	9.2	8.5	4	15.0	6.5	76.47
Butte...........	5	5.0	Colusa	5	9.2	7.1	6	13.8	6.7	94.37
Eureka..........	4	10.0	Caloro	5	7.8	8.9	1	12.0	3.1	34.83
Colusa..........	5	9.2	Caloro	5	7.8	8.5	1	14.0	5.5	64.71
Average.......										67.60

TABLE 4.—*Average yield, in grams, of F_1 plants in comparison with the parental plants, at Biggs, California, in 1924.*

Female parent	Number of plants	Average yield in grams	Male parent	Number of plants	Average yield in grams	Average yield of parents in grams	Cross		Increase in hybrids over parents	
							Number of plants	Average yield in grams	Grams	Percentage
Caloro..........	5	11.0	Colusa	5	15.5	13.2	4	29.9	16.7	126.52
Butte...........	5	9.3	Colusa	5	15.5	12.4	6	32.8	20.4	164.52
Eureka..........	4	29.4	Caloro	5	11.0	20.2	1	33.1	12.9	63.86
Colusa..........	5	15.5	Caloro	5	11.0	13.2	1	24.5	11.3	85.61
Average.........										110.13

Even though the number of plants used in this study is small it seems evident that with respect to yield, these crossed plants exhibit hybrid vigor or heterosis to a marked extent.

SUMMARY

Hybrid vigor has been reported for many species of plants by numerous plant breeders.

The rice crop is grown under conditions which makes hybridization in the field difficult. Rice flowers are delicate and easily injured, which makes artificial crossing a difficult process.

Data are reported in this paper on the hybrid vigor of F_1 plants in comparison with the parental plants for four crosses of rice. Height of plant, length of panicles, culms per plant, and yield per plant are used as a basis for comparing the relative vigor of the F_1 and parental plants.

In the data presented there is some evidence of hybrid vigor for height of plants, little evidence with regard to length of panicles, but marked evidence of hybrid vigor for number of culms and yield per plant of the F_1 in comparison with the parental plants.

RELATION OF THE SEED COAT OF FETERITA TO THE RATE OF WATER ABSORPTION AND GERMINATION[1]

A. F. Swanson[2]

Feterita is an important grain sorghum in the semiarid region of the Great Plains area because of its ability to produce a crop with limited rainfall. Its popularity is lessened, however, by the fact that it is not always possible to secure good germination comparable with that of most other crops under unfavorable weather conditions. If cold and rainy weather follows the planting of this crop, germination and the resultant stand are often so reduced that it is necessary to replant. Observation, on the other hand, indicates that feterita can be planted in a drier seedbed than many of the other sorghums and still produce a good stand. All of these considerations led to an investigation of the permeability and structure of the seed coat of feterita in comparison with that of several other sorghums, and of its moisture requirements for germination in comparison with winter wheat and corn, as factors having a possible bearing on its adaptability.

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[1] Paper presented at the meeting of the Western Section of the American Society of Agronomy held at Ft. Collins, Colorado, June 18–20, 1925. Received for publication March 3, 1926.

[2] Assistant Agronomist, Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture, in charge of cereal investigations at the Ft. Hays Branch Experiment Station, Hays, Kans., in cooperation with the Kansas Agricultural Experiment Station.

EXPERIMENTAL METHODS

The ability of the seed to absorb water was used as a measure of relative permeability. All of the kernels were first carefully sorted for soundness. Glumes were removed. The seed was then dried to a constant weight in a desiccator and was next soaked for different periods in distilled water kept at a constant temperature of 27°C. in a germinating oven. At the end of each interval the seeds were removed from the water and were gently rolled over blotters and filter papers to remove surface water. They were then weighed and immediately replaced in the water to await the next weighing period.

ABSORPTION OF WATER

The first permeability test was made with feterita in comparison with Blackhull kafir, Red Amber, and Kansas Orange. Seven different weighings were obtained, the first four being made at two-hour intervals and the last three at longer intervals. The intervals of weighing and the water absorption are shown in Table 1.

TABLE 1.—*Absorption of water by feterita, Blackhull kafir, Red Amber, and Kansas Orange*

Kind of seed	Number of kernels used	Air dry weight in gms	Water absorbed, expressed in percentage of weight of seed						
			2 hrs	4 hrs	6 hrs	8 hrs	24 hrs	32 hrs	72 hrs
Feterita	179	8	19.8	26.0	33.9	34.4	42.4	43.5	45.3
Blkhl kafir	275	8	13.9	18.6	22.6	25.6	35.9	36.8	39.7
Red Amber	427	8	13.5	19.9	24.5	27.3	36.0	37.4	43.8
Kansas Orange	380	8	24.5	31.5	34.8	36.9	43.0	43.8	[a]

[a] Seed had swollen and disintegrated so that weight could not be taken.

The results indicate that the water absorption of feterita and Kansas Orange was greater and more rapid than that of Blackhull kafir or Red Amber.

Data from a second test with feterita alone in which the weighings were made at half-hour intervals during a three-hour period are recorded in Table 2. In this instance the temperature of the water was held at 29°C.

TABLE 2.—*Rate of absorption of distilled water at half-hour intervals for a three-hour period*

Kind of seed	Air dry weight in gms.	Water absorbed, expressed in percentage of weight of seed					
		½ hr	1 hr	1½ hrs.	2 hrs	2½ hrs.	3 hrs.
Feterita	8	10.37	15.37	18.5	20.75	22.25	23.75

From the above data, the rate of absorption is most rapid during the first hour of soaking The percentage of water absorbed at the end of the two-hour period corresponds closely to that given for the same period in Table 1

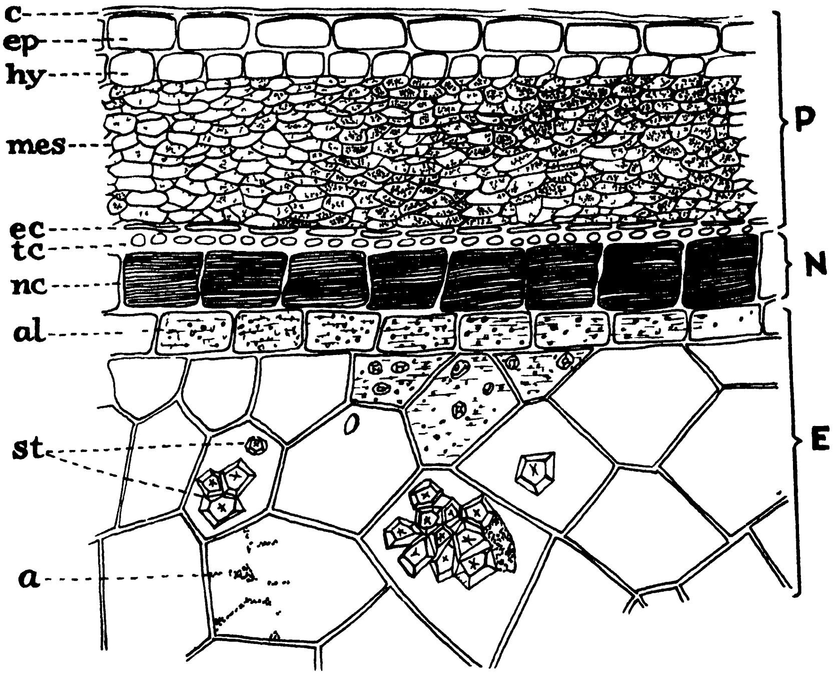

FIG 1 - A schematic transverse section of a portion of a feterita seed *P*, pericarp, consisting of the cuticle *c*, the epidermis *ep*, the hypoderm *hy*, the starch-containing mesocarp *mes*, the cross cells *ec*, and the tube cells *tc*, *N*, nucellar or hyaline layer consisting of thick-walled, pigment-containing cells, *E*, endosperm, consisting of aleurone *al*, and the starch cells containing starch granules *st* and protein bodies *a*

STRUCTURE OF THE SEED COAT

As a factor affecting permeability, the structure of the seed coat was also studied Feterita seed is dull white in color and has a soft, chalky, porous seed coat, while that of Blackhull kafir is of a much higher degree of glossiness and hardness The seed coat of Red Amber is somewhat similar to that of Blackhull kafir The seed coat of Kansas Orange is lacking in lustre, but from outer appearance does not seem to be as soft as that of feterita

A microscopic study was made of seeds of feterita, Blackhull kafir, and Red Amber in cross section A schematic drawing of a part of a feterita seed in cross section is shown in Fig 1

The general structure of the pericarp was the same in the three varieties, except that the mesoderm cells were of greater thickness in feterita. The mesoderm cells are filled with starch granules, and therefore probably have the ability to absorb water rapidly. The larger number of mesoderm cells in the feterita seed may account for it absorbing water more rapidly than Blackhull kafir and Red Amber.

The hyaline or nucellar cells were found as a single prominent layer in feterita and Red Amber but were not present in Blackhull kafir. Since there was little difference in the rate of water absorption by seeds of Blackhull kafir and Red Amber and since the former is without a hyaline layer while the latter possesses it, it seems doubtful whether this particular structure has much bearing on relative permeability.

So far as structure is concerned, it would seem that a seed with a hard glossy outside covering does not permit the entrance of excess water as readily as seed with a soft chalky seed coat of the feterita type. In addition, a hard glossy seed coat is less easily penetrated by fungi, nor does the smaller amount of starch-bearing mesoderm tissue near the seed surface offer as favorable a medium for the fungi as that of the soft-coated, starchy feterita.

MOISTURE REQUIREMENT FOR GERMINATION

Seed of feterita, Kharkof winter wheat, and Pride of Saline white dent corn were placed in a drying oven for 100 hours at a constant temperature of 29°C. The seed was then placed between moistened blotters and put in a desiccator partly filled with water, the desiccator being placed in a germinator and a constant temperature of 29°C. maintained. The blotters were moistened from time to time. The results of the experiment are given in Table 3.

TABLE 3.—*Moisture required to germinate feterita, wheat, and corn.*

Kind of grain	Oven dry weight in grams	Percentage of moisture absorbed and moisture content at which germination occurred		
		48 hrs.	72 hrs.	96 hrs.
Feterita...	8	32.8[a]	42.0	41.3
Wheat..	8	41.3	45.9	48.0[a]
Corn...	16.6	28.5	33.4[a]	34.7

[a]Indicates the time at which germination occurred.

These results indicate that feterita will germinate more rapidly than either corn or wheat and at a lower moisture content. For this reason it is naturally more subject to heating than the latter two crops. As previously mentioned, the ability of feterita to germinate in a comparatively dry seedbed is one reason for its adaptability in dry regions. When planted in a cold, wet seedbed, on the other hand, the seed often rots and a poor stand results because of the bad effect of excess moisture

SUMMARY

Feterita is a desirable dry land crop, but difficulty is often experienced in securing a good germination and stand if wet weather occurs at planting time.

The greatest rate of absorption of water in the sorghum varieties studied occurred during the first two hours of soaking. Water absorption was more rapid in feterita and Kansas Orange than in Blackhull kafir and Red Amber.

Feterita and Kansas Orange have soft seed coats, while Blackhull kafir and Red Amber have hard glossy seed coats. The indications are that a hard glossy seed coat retards rapid water absorption. The mesoderm cells appeared to be of greater depth in feterita than in kafir or Red Amber. These mesoderm cells, though a part of the seed coat, are filled with starch granules and probably account for feterita absorbing water more rapidly than either Blackhull kafir or Red Amber.

The hyaline layer was present in feterita and Red Amber, but absent in Blackhull kafir. The slight difference in the rate of water absorption between Blackhull kafir and Red Amber indicates that the hyaline layer is not a factor in the relative rates of water absorption.

Feterita germinated in a much shorter time than either wheat or corn. Feterita germinated at a moisture content about the same as corn, but much lower than that of wheat.

A STUDY OF THE HISTORY, MANAGEMENT, AND CARRYING CAPACITY OF NEW YORK PASTURES[1]

M. F. Abell[2]

(Abstract)

In the summer of 1916 a study by the survey method was made of the pastures in four areas in New York to determine the importance of some of the factors influencing production from pastures and to obtain data on which to base future pasture work. Data on pastures of 272 farms were obtained, 101 in Tompkins County, 82 in Delaware County, 32 in Livingston County, and 57 in Jefferson and St. Lawrence Counties. Carrying capacity was the factor on which the comparisons were made, and was shown in five ways: (1) Animal unit days per acre on pasture; (2) animal units per 100 acres of pasture; (3) acres per animal unit on pasture; and (4) production in pounds of true protein and therms of net energy from pasture per acre. Armsby's tables for maintenance and production were used.

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[1] Abstract of paper read at the ninth annual meeting of the New England Section of the Society held in Boston, Mass., October 31, 1924. Received for publication March 4, 1926.

[2] Assistant Professor of Farm Management, Massachusetts Agricultural College, Amherst, Mass.

The carrying capacity is influenced by the several natural factors of climate, topography, and soil, and by those factors of history and management that have resulted from various attempts to improve pastures. The data indicate strongly that the older pastures, unless grasses and clovers have been crowded out by a weed better adapted to less fertile soils, produce more and better herbage than those pastures the soils of which have been depleted in fertility by cropping within about 20 years or at the period immediately following the agricultural depression of 1893. There seems to be a certain relation between age of pasture and herbage, but in general it is a question of more weeds as a result largely of decreasing fertility.

The history of the pastures studied is not clear in enough cases to indicate definitely what effect age and management have had on herbage. It is shown, however, that after 20 years or so there is little change in herbage, at least no greater than might result from a change in growing season rainfall of 3 or 4 inches or the rapid spread of an introduced weed. Previous treatment, unless recent, likewise has little effect on pastures. Cropping, unless it has taken place within recent years, does not affect carrying capacity materially unless weeds have so run out the grasses by decreasing fertility as to make renovation necessary. Whether or not pastures have been seeded, provided 20 years or more have elapsed since seeding, also has little effect on pastures. Bluegrass and white clover on suitable soils, and redtop and the bent grasses on those not suited for bluegrass, come in so freely that where pastured heavily less permanent grasses and clovers are soon crowded out by the more permanent herbage and by weeds.

Where fertilization has been practiced, even though not recently, certain beneficial results are seen. In both Delaware and the northern counties land plaster and lime were sometimes hauled several miles for pasture application. The most recent applications, within 12 or 15 years, have held more bluegrass than would be expected on much of these soils. Some very few pastures or parts of pastures have been cropped one year, heavily fertilized, reseeded, and turned back to pasture. These plats are very productive even after 10 or 15 years, but are too small in area to affect total production and the practice is too expensive to apply to large areas for pasture only.

All these data indicate that the practices have little effect after 20 years, or that the herbage by that time has become more or less stable and that fertility is returned about as rapidly as it is used up.

DISCUSSION

Director S. B. Haskell in discussing this paper pointed out the necessity of securing facts, such as presented, to be used later in connection with the reclamation of so-called "marginal" lands.

PASTURE IMPROVEMENT PROJECTS OF CONNECTICUT AND MASSACHUSETTS[1]

HENRY DORSEY[2]

(Abstract)

In Connecticut preliminary and exploratory test plats were laid out in 1919. The number of fields has been extended until at present there are some 50 cooperative tests in different parts of the state. Chemicals, manure, and ashes have been applied. These tests have shown: (1) That the physical character of the soil is of primary importance, and that in times of drouth sandy soils are not productive under any treatment; and (2) that on soils sufficiently heavy to retain adequate moisture acid phosphate and lime tend to bring in white clover. Wherever white clover grows well bluegrass soon thrives.

Connecticut's pasture grazing project was started in 1920. Young beef steers are turned into each of the 4-acre plats and their growth is taken as a measure of the effects of the chemical treatments. Fertilizers were applied first in 1924. Results to date are shown in Table 1.

In western Massachusetts a number of outlying exploratory tests have shown the value of acid phosphate and basic slag in encouraging the growth of white clover and bluegrass to the partial or total exclusion of moss, cinquefoil, and other weeds. In 1921, a series of 10 preliminary plats was laid out on Gloucester sandy loam at the

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[1] Abstract of paper read at the twelfth annual meeting of the New England Section of the Society held in Boston, Mass., December 5, 1925. Received for publication March 4, 1926.

[2] Professor of Agronomy, Connecticut Agricultural College, Storrs, Conn

Experiment Station. In 1922, the number was extended to 132. The plats are 1 square rod in area and the treatments were in sextuplet, as follows:

1. Acid phosphate, 480 and 960 pounds per acre.
2. Ground limestone, 2,400 pounds per acre.
3. Muriate of potash, 80 and 160 pounds per acre.
4. Nitrate of soda, 160 pounds per acre.

TABLE 1.—*Treatments and gains made by young steers the first two years in Connecticut pasture grazing project.*

Plat No.	Rating 3 years	Pounds of fertilizer, applied in 1924[a]	Cost	Gains in pounds			Net gain in pounds	Cost per pound of gain
				1924	1925	Total		
1	83	2,000 L, 500 AP	$60.00	337	764	1,101	604	$0.099
2	102	500 AP	20.00	573	613	1,186	689	0.029
3	100	2,000 L, 100 KCl	49.00	164	390	554	57	0.859
4	86	100 KCl	9.00	165	250	415	−82	
5	97	Check	——	249	248	497	——	
6	101	2,000 L	40.00	230	425	655	158	0.263
7	86	500 AB and 100 KCl	29.00	446	648	1,094	597	0.0486
8	91	2,000 L, 500 AP, and 100 KCl	69.00	351	1,003	1,354	857	0.0805
9	102	150 N, 500 AP, and 100 KCl	47.72	787	668	1,455	928	0.0498

[a] L = Lime. AP = Acid phosphate. KCl = Muriate of potash. N = Nitrate.

The first year the potash treatment (with lime) produced the most marked improvement. By 1924 most of the clover had disappeared but it reappeared with the June rains of 1925, being most abundant on plats receiving potash, acid phosphate, and limestone.

The writer is of the opinion that a fair beginning in pasture improvement work has been made in each of the states, but that the problems are increasing rather than decreasing. Some problems demanding attention are:

1. The best use of marginal land sufficiently smooth that it may be plowed. What about the relative productive capacities of such land in pasture and forage crop rotations?

2. The evaluation for forage of the same crop grown on different soil types.

3. Which is better, light or heavy grazing pastures? Is it advisable to use different types of grazing animals, say sheep and cattle, on the same pasture?

4. The best stage of plant development for grazing.

CRITICISM

R. A. Payne, discussing the above paper, stated the need of investigating the basic relation between plant needs and soil types and emphasized the importance of the question of spending time and money on so-called pasture land that is marginal between true pasture land and timber land. In connection with the question of the use of tillable land for pastures the present experiments are inadequate. The initial investment in establishing pastures on tillable land is great; and we need to know how far the farmer can go in this sort of investment and what plants (sweet clover, white clover, bluegrass, etc.) are best to grow for pasture.

THE MASSACHUSETTS BETTER FORAGE CAMPAIGN: IS IT AGRONOMICALLY SOUND?[1]

B. A. Brown[2]

(Abstract)

The writer interprets the Massachusetts better forage campaign as an effort to induce farmers, particularly dairy farmers producing wholesale milk or butter, to grow not only more forage, but forage of a higher feeding value than that commonly raised; and by forcing maximum consumption of this high-grade roughage reduce the cost of the concentrated or purchased portion of the ration to a minimum. It is comparatively easy to better the quality of corn silage, which makes up a considerable portion of dairy roughage, by increasing the percentage of ear corn in the silage. With hay, however, the problem is more complicated. For the growing of clover and alfalfa hays the extension agronomist has made several recommendations.

This paper deals particularly with the recommendations for alfalfa growing. The Massachusetts outline says that alfalfa will not grow if the soil reaction indicates a pH of 5.5, and that the most thrifty stands of alfalfa were found only on soils with pH 6.8 or above. The author cites experimental evidence to show that alfalfa does not grow well at very low or very high pH, but does best with the soil reaction somewhere near neutral. He further states, "this does not mean that good crops of alfalfa may not be secured when a soil shows considerable acidity," and cites evidence to prove it. The author avers that liming for alfalfa may be overdone and that it is not

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[1] Abstract of paper read at the twelfth annual meeting of the New England Section of the Society held in Boston, Mass., December 5, 1925. Received for publication March 4, 1926.

[2] Assistant Agronomist, Connecticut Agricultural Experiment Station, New Haven, Conn.

necessary to add enough lime to neutralize all the acidity if it be added at least a few months before seeding.

The writer takes issue with that phase of the program for alfalfa which states that the primary use of acid phosphate in establishing a seeding is to assist lime in overcoming the toxic action of soil constituents, and cites experimental evidence in support. The question of strain of alfalfa seed best adapted to New England conditions is given brief consideration, and considerable discussion is given the question of the best number of cuttings and time for cutting alfalfa. On the latter point the writer is of the opinion that more investigation is necessary.

CRITICISM

E. P. Robinson, discussing this paper, emphasized the importance of liming and stated that the suggestion of Brown as to the value of early liming needs trial. The experiment stations need to prove that successful alfalfa production can be secured with smaller amounts of lime. The critic stated that alfalfa will live eight to ten years in New Hampshire, and that only Grimm seed should be used. His first preference is for June seeding in clean culture without a nurse crop; second, early spring seeding with a nurse crop. He agrees with the opinion of Brown that there is insufficient evidence on the question of the best number of cuttings for New England conditions.

IS THE CONNECTICUT SYSTEM OF CORN BREEDING THE BEST?[1]

B. C. Helmick[2]

(Abstract)

The author defined the Connecticut system as that of "the use of single and double first generation crosses between strains of corn which have been self fertilized until they might almost be called pure lines." The four general methods of corn improvement are defined as: (1) Selection of seed, using ear type and ear characters as criteria; (2) selection of seed from the yielding ability of the ear or its parent as determined by the ear-to-row test; (3) crossing of varieties and using the first generation seed either direct or as a source of selection; and (4) the use of first generation crosses between self-fertilized strains of corn—the Connecticut system.

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[1] Abstract of paper read at the twelfth annual meeting of the New England Section of the Society held in Boston, Mass., December 5, 1925. Received for publication March 4, 1926.

[2] Assistant Professor of Agronomy, University of Maine, Orono, Me.

The most important of the experiments with each method were historically reviewed.

Briefly, conclusions were drawn as follows:

1. Ear characters are of no practical value as indices of yield in corn breeding. Nevertheless, some workers claim that in selecting seed for general planting certain ear types are more likely to give good yields than are other types. The majority of investigations have shown that long-continued selection of any one type or character is likely to result in reduced yield.

2. Of the eight reports summarized, three find no significant value of ear-to-row breeding over field selection, one finds conflicting results, and four find quite uniformly positive results by the use of some form of ear-to-row selection.

3. Results of variety crossing show a few crosses that yield less than the poorer parent, a few show yields considerably above the better parent, and the majority show yields intermediate between the parents. Some of the crosses outyield both parents under one set of conditions and yield less under others.

4. The increasing volume of work with the F^1 crosses between pure lines shows that, while this method will not always give yields greater than those of the original varieties, it will do so in the majority of cases and will usually give yields above those of the best commercial varieties—in some cases 100% higher. This system is considered one of the most promising methods of corn breeding.

A bibliography of 21 references is attached to the original paper.

DISCUSSION

C. A Michels, in discussing this paper, emphasized the importance of genetic research in corn improvement projects and stated that "this (Connecticut) system far surpasses the other methods in every detail, and comes nearer solving the problem of increasing economic production and quality than any of the other methods."

SUPPLEMENTING THE DIMINISHING MANURE SUPPLY WITH REFERENCE TO THE MARKET GARDENING INDUSTRY IN MASSACHUSETTS[1]

R. M. KOON[2]

(Abstract)

The situation was surveyed with reference to (1) the diminishing supply of manure, (2) its cost, and (3) the importance of manure in market gardening. Due to the displacement of horses by motor vehicles in urban commercial centers, the supply of manure is annually decreasing. The complete disappearance of horse manure in quantity is inevitable. The middleman has entered the business of supplying manure to the farmer. At present, in the vicinity of Boston, city manure purchased through a middleman costs the farmer $5.00 per ton on the land, without considering a 25% shrinkage.

The author stated: "There is a universal agreement that the all-important factor in growing vegetables is humus." Quality depends upon vigorous uninterrupted growth; the soil must be quick. "Organic matter is essential for this condition... The vegetable grower knows that in no better way can he improve and maintain the proper soil texture than by heavy applications of manure."

Market gardeners were classified into two groups in their relation to the manure supply. First, there is the suburban market gardener who farms on very high-priced land with high-priced labor. He has ready access to such city supplies of manure as are available. In his case there is not the present necessity for growing manure substitutes that prevails with the second type of gardener, as his land and labor are too costly to be utilized for growing green manure crops. He should know, however, how much manure he actually needs to maintain the supply of organic matter and what proportion of the fertility could be supplied in chemicals.

The second type, the rural market gardener, does not crop his land so intensively, his production costs are not so high, and consequently he has more opportunity to grow green manure crops.

Both types of market gardeners are supplementing the manure with chemical fertilizers. It may be only nitrate of soda or sulfate of ammonia as a side dressing in certain cases; but the majority are

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[1] Abstract of paper read at the twelfth annual meeting of the New England Section of the Society held in Boston, Mass., December 5, 1925. Received for publication March 4, 1926.

[2] Extension Professor of Vegetable Gardening, Massachusetts Agricultural College, Amherst, Mass.

using a 5-8-7 (figures refer to percentages of NH_3, available P_2O_5, and K_2O, respectively) mixed fertilizer in varying amounts and in an experimental way. Very few growers, suburban or rural, are employing green manures to any extent

The situation with reference to the manure supply is not yet serious as is indicated by the fact that during the eight years the Market Garden Field Station has been in operation less than a dozen inquiries have come in regarding any phase of soil fertility, and in the two years the writer has been associated with the Station not one request has been made for information with reference to manure or manure supplements. At present market gardeners are concerned primarily with problems of seed, labor, and marketing. That manure substitutes and supplements will command more attention within the next few years is inevitable.

Recommendations of the county agent and extension specialist with reference to manure substitutes and supplements are indefinite and non-committal. This attitude is due to the "little experimental evidence available on the subject, and what does exist has not been interpreted with a view to its practical application."

The confusion of ideas existing with regard to truck crops and soil fertility was emphasized and a plea made for serious consideration of the following questions:

1. How little manure can be used each year and yet maintain the right organic content of the soil?
2. How much fertilizer is needed to supplement this manure?
3. What fertilizer ratio is best for general purposes in vegetable growing?
4. What green manure crops are best suited, when should they be planted, what rate of seeding, and when should they be turned under?
5. How much can market gardeners pay for manure, at present prices of vegetables, $4.00, $6.00, or $8.00 a ton?.

CRITICISM

M. F. Morgan, as critic, raised the questions: Is the manure supply actually diminishing? What about the future of horses in cities? What about synthetic manure as a substitute?

"Is it desirable for the experiment stations to interpret their own results and leave to the extension specialist only the task of repeating in a 'parrot-like way the summary given in the last paragraph' of the bulletin?" This last question provoked considerable discussion among those present on methods of extension teaching.

REPLACEMENT OF FARM MANURE BY COMMERCIAL FERTILIZERS IN GROWING TOBACCO[1]

J. P. JONES[2]

(Abstract)

Attention was directed to the diminishing supply of purchasable manure and that produced on tobacco farms. Early experiments by the Connecticut and Massachusetts stations, in which there is some comparison between manure and commercial fertilizers, were reviewed. In the Massachusetts experiments there was no evidence of the superiority of manure and in the early work in Connecticut "there is nothing to show that manure may not be satisfactorily supplemented or even replaced by fertilizer chemicals."

Recent experiments at the Windsor (Connecticut) Tobacco Station show average yields as follows:

4,000 pounds tobacco fertilizer, 1,540 pounds tobacco.

4,000 pounds tobacco fertilizer, plus 10 tons horse manure, 1,514 pounds tobacco.

4,000 pounds tobacco fertilizer, plus 10 tons cow manure, 1,928 pounds tobacco.

Since the tobacco grown with fertilizer alone carried 35% light wrappers, which was slightly in excess of the percentage in that grown with manure, the author is of the opinion that the results with the fertilizer alone are satisfactory. At the Massachusetts Station the average yield for one year from fertilized plats was 1,315 pounds; and from plats treated with the same kind and amount of fertilizer plus about 8 tons of manure, the yield was 1,331 pounds per acre.

Reviewing the results in tobacco growing reported by the Ohio, Pennsylvania, and Virginia experiment stations, the writer concluded that tobacco can be grown continuously, for a short time at least on certain soils, when fertilized with commercial materials alone. It does not follow, however, that it is a sound practice economically or from the standpoint of soil fertility. It is recognized that replacing manure with commercial fertilizers means that a soil continuously cropped with tobacco may be seriously depreciated in its organic matter content.

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[1] Abstract of paper read at the twelfth annual meeting of the New England Section of the Society held in Boston, Mass., December 5, 1925. Received for publication March 4, 1926.

[2] Assistant Professor of Agronomy, Massachusetts Agricultural College, Amherst, Mass.

Bearing on the question of supplying organic matter by means of green manures, cover crops, and crop residues, are data from Ohio, Connecticut, Massachusetts, and the United States Department of Agriculture. These were briefly reviewed. Benefits have resulted where tobacco rotated with wheat and red clover, but for shorter rotations, even where clover was used, the results have not been so favorable. At the Massachusetts Station results for 1924 and 1925 show a depressing effect on yield from the use of timothy as a cover crop.

"It is quite evident that attempts to supply through other means the organic matter furnished by stable manure, but missing in commercial fertilizers, have not been promising. This raises the question, Is the organic matter of manure essential to good yields and high quality of tobacco?"

CRITICISM

B. G. Southwick, discussing the above paper, stated it contained a very good summary of the literature but did not answer the question, "What are we going to do about it?" More information is needed as to the importance of organic matter in growing tobacco, the advantages and disadvantages of legumes as green manures, and a substitute for timothy as a cover crop to prevent blowing

CONCENTRATED FERTILIZERS: WHAT ARE WE TO DO ABOUT THEM?[1]

A. B. BEAUMONT[2]

(Abstract)

In recent years chemical engineering has made available for use as fertilizer materials certain compounds, rich in plant nutrients, which were formerly too expensive for such purposes. The question as to possible injury to the plant by these concentrated fertilizers, singly or mixed, has been very definitely raised. The two possible causes of injury, plasmolysis or "burn," and poisoning were discussed in their theoretical and practical aspects. "Burn" caused by too great concentration of soluble material in the immediate vicinity of the root is regarded by many as the more serious possibility; whereas,

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[1] Abstract of paper read at the twelfth annual meeting of the New England Section of the Society held in Boston, Mass., December 5, 1925. Received for publication March 4, 1926.

[2] Professor of Soils, Massachusetts Agricultural College, Amherst, Mass.

the bad effects of small amounts of toxic substances, for example boron compounds, may be much more serious and difficult to cope with.

Experimental work was reviewed. Until within about the last seven years when the problems of the use of concentrated materials became urgent, almost all the experimental work that had any bearing on the question was that relating to the problem of tolerance of "alkali" salts by plants. Data from some of the western states throw some light on tolerance of plants for soluble fertilizer materials.

Most of the actual tests of concentrated fertilizer materials have been conducted in England and Europe where the problem is more urgent than in America. Results to date show that the nitrate, chloride, phosphate, carbonate, bicarbonate, and sulfate-nitrate of ammonia, calcium nitrate, calcium cyanamide, urea, and urea salts rank well with nitrate of soda and sulfate of ammonia. In this country we have results reported from Alabama, New Jersey, and Massachusetts. During 1924 and 1925 at the Massachusetts Station raw materials, home-mixed, and commercially mixed goods were tested on a variety of crops. Results show some reduction in germination or stand when concentrated mixtures were applied in the row, but the yields were as good or better with concentrated as with ordinary materials.

A brief discussion of the amounts of fertilizers that may be used was presented and then the question was asked: "As agronomists, what shall be our stand with reference to concentrated fertilizers?" The writer proposed that "our recommendation in general will be for the material which furnishes a unit of plant nutrients at the lowest cost, that there is in our fertilizer economics a place for both classes of materials, and that each material be considered in the light of available knowledge concerning it."

Suggestions for test and research work were given and a bibliography of 13 references was appended to the original paper.

CRITICISM

B. L. Hartwell, in criticism, stated that he agreed that unit cost of plant food is of prime consideration. Agronomists are not so interested in tolerant limits of plants for fertilizer as they are in the economic response of different crops to fertilizer materials. The question of distribution of fertilizers in the soil is of prime importance.

NOTE

SOME ASPECTS OF FREEZING INJURY TO WHEAT IN INDIANA IN 1925

On May 25, 1925, a sudden drop in temperature caused serious injury to the heads and stems of wheat in the northern two-thirds of Indiana. Wheat had been making a rapid growth because of the unusually favorable spring, in the southern half of the state it was headed and was jointed in the northern part. As a result the nature of the injury was quite different in various parts of the state.

The state weather reports give a clear conception of the temperature condition occurring in May. During the 11-day period between May 9 and May 20 the average temperature for the entire state was about 65°F., while from May 21 to May 24 it was unseasonably warm. Many stations reported a maximum of over 90°. These high temperatures, moreover, were not confined to the southern part alone. Without doubt it was this exceptionally favorable weather which caused the rapid growth of the wheat. Following the summer temperatures of May 24 came the cold wave. The minimum temperatures of the state ranged from 27° to 36°F., and again the records show that in the southern quarter of the state the average was above 32°, while north of this region the minimum was below freezing.

Observations made in 15 counties during the month of June gave an indication of the nature of this freezing injury, its relation to the development of the wheat plants, and the areas affected. For a period of about ten days or possibly two weeks it seemed that no harm had been done to the wheat, but early in June the injurious effects were apparent. The experience of one Rush County farmer typifies this condition. Following the freeze he made frequent examinations of his wheat by going through the field at least two or three times a week. Previous to Monday, June 15, he stated that his prospects for wheat were never better, but at this time he noticed that the wheat was drying up and that the stems were becoming sticky. In DuBois, Vanderburg, Knox, and Sullivan Counties no evidences of injury were found but north and northeast of this area the injury was common, though not occurring in all fields. These observations coincide with the weather records, showing that the freezing temperatures occurred in the northern three-quarters of the state.

The type of injury seems to depend on the stage of development of the wheat. Where the wheat was in head at the time of the freeze the individual spikelets seem to act independently in their resistance to the injury. In Rush, Shelby, Bartholomew, and adjacent counties all gradations of injury could be seen. In some heads only one or two spikelets were killed while others were completely destroyed. In some cases only the terminal spikelets were killed, in other cases the lower thirds were destroyed, and in still others the affected spikelets occurred in the mid portion of the head. In all such heads the unaffected spikelets developed to a rather abnormal size giving the head a peculiar appearance. The frozen spikelets had a water-soaked appearance at first, but they soon dried out and shriveled. In some instances the injury in this region seemed to be localized in the stem immediately below the head which was apparently uninjured.

Further north in the state where winter injury occurred and the wheat had not yet headed, the entire head was killed and the plants were greatly dwarfed. Some fields were observed in which not more than 1% of the heads developed, though in no cases were the plants completely destroyed. In these regions another type of injury occurred. The tissues of the stem immediately above the top node became soft and flabby and during the morning following the freeze these frost-damaged plants could be detected by pulling the head. The frosted stems broke at the junction of the node and stem permitting the stem to be pulled easily from the sheath, while those not affected remained intact. The heads of such frost-injured plants seldom emerged from the boot and those that did were never filled.

About a month after the freezing of the wheat a new development appeared. Those plants on which the head had been destroyed developed a deep bluish purple color in the stems and sometimes the leaf sheath. It may be stated in passing that the same condition also may prevail in wheat plants having the heads destroyed by loose smut. Associated with this color was a heavy accumulation of one or more of the sugars. In some cases this accumulation was so great that a sweet sticky syrup actually exuded on the surface of the stems. A peculiar incident in Bartholomew County first called attention to this condition. While certain farmers were cutting their wheat, the horse's legs, the men's clothing, and the canvas of the binder became heavily coated with this sticky substance. It caused some difficulty in cutting the wheat and much wonderment among the farmers. They stated that it was necessary to wash off the horse's legs each night and that the binder canvas became stiff and rather difficult to operate.

It was only necessary to heat pieces of the stems of this frosted wheat in Fehling solution to demonstrate the sugar present.

Heavy red deposits of copper occurred both in the bottom of the test tube and in the tissues of the treated stems. Tests of this kind were made with frosted wheat from many parts of the state and in every case the sugar reaction was secured. Repeated tests with normal wheat stems never gave this reaction nor did the stems of wheat in which the heads had only been partially destroyed by the freeze and in which the remaining spikelets developed wheat.

During the normal development of the wheat plant the sugars developed photosynthetically in the leaves are transferred, in part at least, to the head. With the destruction of the tissues or of the head of the stem these sugars accumulated in the stem and were the probable cause of the deep coloration. Further evidence justifying this explanation is that the sugar accumulations and the deep color always extended to the point of injury wherever that might be and also that it never occurred when a normal wheat head was produced nor did it occur when a few spikelets remained alive on the partially frozen heads.

Varieties of wheat made different responses to the frost injury. In Starke County in northwestern Indiana, it was noted that Kanred and Michikoff were uninjured, while other varieties were seriously affected. In Bartholomew, Shelby, and Rush Counties, Purkoff and Michikoff were not affected by the low temperatures, while varieties like Red Chaff, or Goens, and Rudy showed the injuries described above. Both Purkoff and Michikoff are hybrids of Michigan Amber and Malakoff developed by the Purdue University Agricultural Experiment Station, and the latter is a hard red winter wheat. They are slightly later than these other varieties in developing, but this factor apparently was not responsible for their resistance for other wheat in the boot at the same time was severely injured. Evidently their resistance to the freezing injury is due to the inherent hardiness of these varieties.—C. T. GREGORY and K. E. BEESON, *Purdue University Agricultural Experiment Station, Lafayette, Ind.*

AGRONOMIC AFFAIRS

MINUTES OF MEETING OF NEW ENGLAND SECTION OF THE SOCIETY

The New England Section of the American Society of Agronomy met at Boston, Massachusetts, December 4 and 5, 1925, for their 12th annual conference. Thirty-six to forty agronomists and others interested in agronomy were present at the various sessions. The following program was carried out.

Director W. L. Slate, Jr., presiding

December 4, 6:30 p. m. Dinner, followed by smoker and informal discussion of topics of interest, including:

New England's dairy marketing problem: What are we doing about it? J. D. Willard, Director of Extension Service, Massachusetts Agricultural College.

Reports of the Chicago meetings.

Committee reports, as follows:

1. Director B. L. Hartwell, reporting for the Committee on the Revision of the New England Standard Nine Grades of Fertilizer, appointed in 1923, moved that the report of the Committee as submitted last year (Jour. Amer. Soc. Agron., 17:1; 68–72) be taken from the table and adopted. After some discussion the motion was lost, and it was then voted to continue the Committee with instructions to reconsider the question and report at the next meeting.

2. Professor M. G. Eastman, reporting for the Committee on Alfalfa and Clover, stated that certification of seed as to source of production was the main problem, and that some progress had been made in securing dealers to handle such seed. The report was adopted.

3. Professor J. S. Owens submitted a written report of progress for the Committee on Freight Rates for Lime. A quantity of information on railroad tariffs has been collected. Among other facts ascertained was that crushed rock carries a tariff of 70 cents per ton within the same district in Connecticut in which ground limestone carries a charge of $1.80 per ton. The Committee was continued.

4. Professor A. B. Beaumont submitted the following report for the Committee on Soil Classification:

"The committee is of the opinion:

"1. That for New England conditions the present number of textural distinctions used by the U. S. Bureau of Soils is not justified by agronomic experience, and that textural classification should be made without the use of the terms silty clay loam and sandy clay.

"2. That the ambiguity of terms used in textural classification is confusing and that a careful study of terminology should be made looking toward clarification."

5. B. G. Southwick reported for the Committee on Crystallization of Opinion of the current meetings as follows:

1. Progress is being made on pasture improvement projects, but there is yet much to be done. These projects should be continued.

2. The policy of securing the growth and utilization of more and better roughage including alfalfa, by the dairy farmers, should be kept to the front by both experiment stations and extension services of New England.

3. The Connecticut corn improvement methods should go ahead in the field of securing improved F_1 strains available for more general use.

December 5, 8:00 a. m.

General theme: "What are we going to do about it?"
Scope: Primarily research and extension activities related to the outstanding agronomic production of New England.

1. Are the pasture improvement projects of Connecticut and Massachusetts adequate?
Analyst: H. E. Dorsey. Critic: R. A. Payne.
(Abstract printed elsewhere in this issue)

2. The Massachusetts Better Forage Campaign: Is it agronomically and economically sound?
Analyst: B. A. Brown. Critic: E. P. Robinson.
(Abstract printed elsewhere in this issue)

3. Is the Connecticut system of research on corn breeding on the best basis?
Analyst: B. C. Helmick. Critic: C. A. Michels.
(Abstract printed elsewhere in this issue)

4. Supplementing the diminishing manure supply with specific reference to:
a. Market gardens and Rhode Island experiments.
Analyst: R. M. Koon. Critic: M. F. Morgan.
(Abstract printed elsewhere in this issue)

b. Tobacco.
Analyst: J. P. Jones. Critic: Benjamin G. Southwick.
(Abstract printed elsewhere in this issue)

5. Concentrated fertilizers: What are we to do about them?
Analyst: A. B. Beaumont. Critic: B. L. Hartwell.
(Abstract printed elsewhere in this issue)

The original papers, abstracts of which are printed elsewhere in this issue, are on file and access to them may be had by addressing the secretary of the New England Section.

At the business meeting, which followed the above program, the following officers for the ensuing year were elected: A. B. Beaumont, Massachusetts Agricultural College, *President;* F. S. Prince, University of New Hampshire, *Secretary.*

ANNUAL MEETING OF THE CORN-BELT SECTION OF THE SOCIETY

The annual mid-summer meeting of the Corn-belt Section of this Society will be held at University Farm, St. Paul, Minnesota, on July 15, 16 and 17, 1926. A program of inspection and discussion will be followed, with some side trips to points of interest. Two or three other societies with allied interests are planning to meet at University Farm at the same time.

"AGRONOMY—CURRENT LITERATURE"

The library of the Bureau of Plant Industry of the United States Department of Agriculture has inaugurated a bi-weekly issue of a mimeographed list, under the above name, of titles of articles appearing in current journals, books, station and Department bulletins, etc. The list begins with articles appearing in the literature of 1926. Sample copies of the list may be secured by agronomists by applying to the Bureau Librarian.

JOURNAL
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SYMPOSIUM ON "BASE EXCHANGE PHENOMENA IN SOILS"

Leader: RICHARD BRADFIELD, University of Missouri

1. "A General Discussion of Base Exchange in Soils." W. P. Kelley, University of California.
2. "The Relation Between the Electrokinetic Behavior and the Base Exchange Capacity of Soil Colloids." Sante Mattson, Bureau of Soils, U. S. Department of Agriculture.
3. "Base Exchange in Soil Colloids and the Availability of Exchangeable Calcium in Different Soils." F. W. Parker and W. W. Pate, Alabama Agricultural Experiment Station.
4. "Reciprocal Repression by Calcic and Magnesic Additions in Surface Soil." W. H. MacIntire, Tennessee Agricultural Experiment Station.
5. "The Effect of the Nature of the Exchangeable Bases upon the Retention of Anions by Soils." C. H. Spurway, Michigan State College.

General Discussion.

1. A GENERAL DISCUSSION OF BASE EXCHANGE IN SOILS[1]

W. P. KELLEY[2]

The fact is well established that an exchange of bases takes place when a soil is treated with certain salt solutions. As is well known, Way (9)[3] noted three-quarters of a century ago that when a sample of soil was treated with a solution of potassium chloride, or certain other neutral salts, a part of the base of the salt was absorbed by the soil and an equivalent amount of calcium passed into the solution. He also noted that the anions of neither the soil nor the salt were affected by the treatment. It was only the bases that were concerned. These facts have since been verified with soils from various parts of the world. Investigation has shown that the exchange property is characteristic of soils in general.

Although the subject has been investigated for many years, it is only within the past 10 or 15 years that the study of base exchange has been placed on a reasonably satisfactory quantitative basis, and only recently that its importance has been widely recognized. In this connection special credit is due to Gedroiz (3, 4)[4] of Russia. Paralleling his work, although quite independently, Hissink (5) of Holland has made almost, if not quite, as important a contribution to the subject and has drawn conclusions remarkably similar to those of Gedroiz. The serious student of the subject will find a source of great stimulation and suggestion in the work of these two men. The foundation was laid, however, by Way. Gans (1, 2), in connection with his extensive investigations on artificial zeolites, and various others, have contributed to the subject. Some of the more important phases of alkali soils as related to base exchange are strongly suggested by Gans' experiments, both with normal soils and with artificial zeolites.

The exchange compounds of soils, or complex as it is frequently called and which I consider to be composed of complex salts of alumino-silicic and organic acids, exert an important influence on the H-ion concentration of the soil solution. As Gedroiz (3) has shown, the exchange reaction is equally involved in, and lies at the very foundation of, certain conditions met with in the acid soils of humid regions, on the one hand, and the peculiar properties of alkali soils of arid regions, on the other hand. In the former case we have to do with the product resulting from the action of dilute acids on the exchange compounds. In the latter case it is the product formed by the interaction of soluble salts and the same exchange complex. With mineral soils the first-named product is probably an acid alumino-silicate and the second is a sodium alumino-silicate. The former is acidic because of the nature of its ionization, the latter is alkaline because of hydrolysis, but with acid and alkali soils alike the rôle played by the exchange compounds is fundamentally the same and in both cases it is of far reaching influence.

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[1] Paper read as a part of the symposium on "Base Exchange Phenomena in Soils" at the meeting of the Society held in Chicago, Ill., November 17, 1925.

[2] Professor of Agricultural Chemistry, University of California, Riverside, Calif.

[3] Reference by number is to "Literature Cited," p. 457.

[4] For reference to Gedroiz' earlier papers see Kelley and Brown (7).

Since the solubility and ionization of the acid alumino-silicates, formed by the exchange of hydrogen ions for bases, are low and since, in the absence of $CaCO_3$, dilute acids react very readily with the exchange compounds by ion exchange, it follows at once that the so-called buffer property of soils for acids is influenced by the exchange compounds. When dilute acids come into contact with the exchange compounds bases are brought into solution and H-ions are absorbed. The acid is said to be neutralized or partially so. The amount of exchangeable base present determines the extent to which this reaction can take place. It is a direct measure of the buffer property for acids. Soils that are low in replaceable bases are usually low in buffer action. When acids of biological origin are formed in a soil of low base-exchange capacity, they tend to dissolve aluminum with the resulting formation of toxic conditions.

It follows, therefore, that the composition of the soil solution is influenced by the exchange complex. In the absence of calcium carbonate the calcium of the soil solution is probably derived largely from the exchange complex and, if the soil is well supplied with replaceable calcium, the soil solution will be predominantly a calcium salt solution. Such soil, if adequately supplied with other essential nutrients, is likely to be a fertile soil. If the exchange complex is mainly composed of magnesium compounds, as appears to be the case with certain soils that have been derived from serpentine rocks, the soil solution is likely to contain a preponderance of magnesium salts, and, therefore, it will not be well suited to crop growth. If replaceable sodium predominates, as is the case in certain alkali soils, the soil solution will be alkaline and predominantly a solution of sodium salts. Such soils are toxic to plants even after the removal of the usual water-soluble salts commonly found in alkali soils. If hydrogen constitutes an excessive part of the exchange complex the soil solution is likely to be relatively deficient in calcium and it may contain toxic concentrations of aluminum as well.

The exchange compounds also have some influence on the phosphate content of the soil solution. When the exchange complex is made up of calcium compounds the phosphate content of the soil solution is limited by the solubility of calcium phosphate. If, on the other hand, the exchange complex is composed of sodium compounds, the phosphate content of the soil solution may be considerably greater, due apparently to the fact that the bases which are combined as phosphates tend to be absorbed by the exchange complex as fast as they are dissolved, with the simultaneous formation of the more soluble sodium phosphate.

The exchange reaction is involved in the action of fertilizers. When potassium or ammonium salts are applied there takes place an exchange between the base of the salt applied and the soil bases. With neutral soils it is calcium that is mainly replaced and with acid soils hydrogen ions may also be replaced. The soil solution, therefore, becomes enriched not only in the base applied as a fertilizer but also in constituents originally present in the solid components of the soil. The well-known fixation of potassium and ammonium by soils is due directly to the exchange reaction.

Gedroiz (4), Wiegner (10), and others (7) have shown that the physical properties of soils are also influenced by the exchange complex. When calcium is the predominant replaceable cation the clay particles tend to assume the form of aggregates. The clay is said to be granulated and the soil is relatively porous. The colloids then exist largely in the state of gels, as contrasted with the sol condition. On the other hand, if mono-valent bases, sodium in particular, predominate, the state of the colloids is reversed. The soil then presents a highly dispersed condition. The colloids take the form of hydrosols. If hydrogen constitutes the major part of the exchange complex the physical property of the soil is somewhat intermediate between that of flocculation of the calcium-saturated soil and the condition of deflocculation characteristic of the sodium-saturated soil.

The fertility of a soil as suggested already is intimately related to its exchange capacity. Other things being equal the strength of a soil and its capacity to stand up under artificial husbandry are influenced to an important degree by its content of exchangeable bases. In closing a symposium on base exchange held by the Faraday Society last December, Sir Daniel Hall,[5] who it will be recalled was for many years a leading soil investigator in England and the Director of the Rothamsted Experiment Station, made this very significant and important statement, "A good soil is one that has got a large amount of exchangeable bases. We have seen always that the soils which stand out as the most fertile soils are soils which seem to have been through some maturing process and have been in contact with a great deal of water containing salt such as the silt soils of our astuaries. These are always rich soils which stand up to long cultivation and seem to be the most grateful for manuring. These are soils which seem, as it were, to be loaded with exchangeable bases, and in turning our attention to exchangeable bases we begin to get a better clue to fertility, at any rate from the mineral side, than by any other method of attack that we have yet been able to make upon the soil."

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[5] Trans. Faraday Soc., 20:614. 1925.

The early students of the subject were mainly interested in the solutions that were brought into contact with the soil. It was the fact that potassium or ammonium was absorbed that attracted the chief attention. It remained for Gedroiz first to call attention sharply to the very important fact that the effect of exchanging one base for another is registered both in the solution used in bringing about the exchange and on the solid components of the soil. The soil undergoes a change reciprocal to that of the solution. When the soluble products of the reaction are removed the remaining soil constituents manifest properties different from those of the original soil. But the exchange of bases is not carried to completion by a single treatment with a salt solution. The principle of equilibrium intervenes. However, if the treatment is continued using a fresh solution of the salt, the replacement will proceed still further. Gedroiz and Hissink both showed that under leaching conditions the replacement can ultimately be made complete. Then the soil will contain only that base in replaceable form the salt of which is used in leaching the soil. They further showed that the properties of the soil as a whole are profoundly influenced by the bases which happen to be present in replaceable form.

The base-exchange reaction is influenced not only by the principles of chemical equilibirium but by mass action as well. The extent of the exchange is roughly proportional to the concentration of the salt solution. Very dilute solutions of certain salts may not effect any appreciable exchange. Moreover, Gedroiz has shown that it is apparently not possible to replace all the replaceable calcium by leaching the soil with a dilute solution of salts of the monovalent bases, even though the leaching be continued for an indefinite period. It may require a fairly concentrated solution of these salts to effect complete substitution. The effect of concentration is highly important when we come to consider the exchange resulting from the application of substances of low solubility, such as $CaCO_3$, CaO,

$MgCO_3$, MgO, etc. In fact the concentration of calcium ions afforded by calcium carbonate may be too low to effect any important replacement of magnesium from the ordinary soil and similarly magnesium carbonate may bring about only slight replacement of calcium.

Gedroiz went a step further and showed the complete mutuality of the exchange. Whereas potassium or ammonium can be caused to replace the calcium normally present and thus produce a condition in which the soil will contain potassium or ammonium as the only base in replaceable form, by reversing the condition, the potassium or ammonium can be replaced by calcium and the situation originally present be thus restored. The importance of this fact is very great for it leads at once to a quantitative method for the study of base exchange and makes possible a better understanding of the influence of the several replaceable bases on the properties of the soil. By leaching with a solution of a salt whose base is not present in the soil, such as ammonium salts, the amounts of the replaceable bases can be easily determined.

The European soils that have been studied, exclusive of alkali soils and highly acid soils, appear to be remarkably similar in regard to the relative proportion of the several replaceable bases present. Calcium normally comprises from 75 to 90% of the total, magnesium from 10 to 15%, and potassium and sodium only a few per cent. While the American soils that have thus far been examined seem to be similar to the European soils, occasionally some of our recent soils on the west coast (7) are found to be somewhat different in that magnesium is rather prominent in the exchange complex, but here, as in Europe, the monovalent bases are usually low, excepting alkali soils, of course.

While calcium is normally the principal replaceable base, this fact tells us nothing of the actual amount present and in this regard soils vary greatly. Some soils contain much, some little replaceable base. As Way pointed out in 1850, the exchange reaction is due chiefly to substances residing in the clay fraction of soils. Consequently, heavy types usually contain a greater amount of replaceable bases than the lighter types, but the amount present is not necessarily proportional to the clay content. Clays from different soils may differ considerably in their exchange capacity.

It is important to understand that not all of a given base that is present in a soil is ordinarily replaceable. Among all the soils that have been studied thus far it has been found that only a part of the calcium, magnesium, potassium, and sodium can be replaced. Broadly speaking, the base-containing constituents of soils fall in three classes, *viz.*, (a) crystalline minerals, such as the feldspars, mica, hornblend, etc.; (b) simple salts, such as calcium carbonate, calcium phosphate, etc.; and (c) the amorphous compounds both organic and inorganic. It is with the last named that base exchange is mainly concerned. But the other compounds also have to be considered, especially calcium carbonate, because of solubility complications which arise in the study of the subject.

While under suitable conditions the exchange may be effected by any of the common bases, the different bases, as suggested already, exhibit important differences in their replacing activity. Formerly it was thought that potassium and ammonium have greater replacing activity than calcium. This we now know to be untrue. The well-known fact that a normal soil will absorb greater amounts of potassium or ammonium than calcium from a solution is due to the fact that calcium is usually the chief replaceable base normally present in the soil. If the exchange compounds are first converted into sodium, barium, ammonium, or magnesium compounds, they will then absorb calcium more readily than potassium. The very fact that calcium normally comprises a large percentage of the total replaceable bases is evidence in itself of the affinity of calcium for the exchange complex.

As suggested above, the replaceable bases can be displaced by hydrogen ions. The replacing activity of hydrogen ions is in fact much greater than that of the bases. By leaching a soil with carbonic acid it is possible to bring about a substitution of hydrogen ions for a considerable part of the replaceable cases. When the substitution of hydrogen ions has proceeded to a certain extent the soil exhibits acid properties.

Various investigators have shown that acid soils are able to convert neutral salt solutions into acid solutions. This is due to the exchange of hydrogen ions of soil for the base of the salt solution. Although the exchange of one base for another is completely reversible, the exchange of hydrogen for the base of a neutral salt solution is apparently only partially reversible. An alkaline solution may be required to effect the replacement of the last traces of replaceable hydrogen.

In the study of acid soils from the standpoint of their exchange capacity, especially in the study of soil acidity, it becomes important to determine the exchangeable hydrogen quantitatively. Hissink (6) has proposed a method which consists essentially in the determination of the amount of barium the soil is capable of absorbing from barium hydroxide. We have devoted considerable study to this point. I regret to state that our results lead us to question Hissink's conclusions. The results will be published in the near future.

At present, suffice it to say that soils in general, whether acid, neutral, or alkaline, appear to contain constituents other than the exchange compounds which react with barium hydroxide. We believe that colloidal silica is largely involved. If a soil absorbs barium from barium hydroxide only as a result of the substitution of barium for hydrogen ions in the exchange complex, as Hissink seems to think, the quantity of barium held by the soil after treatment with barium hydroxide plus the amount of other bases present in replaceable form should be chemically equivalent to the amount of some other base, such as NH_4, which the soil is then capable of taking up from a neutral solution of that base. We know, for instance, that by substituting barium for the bases present in replaceable form in neutral soils, the barium can in turn be readily replaced by NH_4 and this replacement takes place by chemical equivalents. It would seem reasonable to assume, therefore, that any barium that is taken up by the exchange complex of an acid soil will also be replaceable by the base of a neutral salt.

Now, applying the concept of mutuality of exchange to Hissink's method for the determination of replaceable hydrogen in soils that are unsaturated with bases, that is acid soils, we find no correspondence whatever between the amount of barium absorbed from barium hydroxide and the amount of replaceable barium that is then present. The conclusion seems to be that strongly alkaline solutions are capable of reacting with soil constituents other than the exchange complex, as well as with the exchange complex itself, and that the amount of hydrogen present in the exchange complex of an acid soil is not necessarily measured accurately by the amount of base which the soil as a whole is able to take up from an alkaline solution.

In my opinion there is good reason for the suggestion made some years ago by Truog (8), namely, that side reactions take place when soils are treated with strong alkalies. Apparently various constituents are reacted upon, colloidal silica being one of the more important. As far as we have been able to go the most accurate measure of base unsaturation referring to the exchange complex, of course, is afforded by first determining the total replaceable bases calculated in terms of chemical equivalents, and then determining the amount of NH_4 which the soil will absorb from a neutral ammonium salt solution after the soil has first been treated with an alkaline solution in excess. The difference between the NH_4 absorbed and the sum of the replaceable bases originally present affords a measure of the replaceable hydrogen ions which can be expressed in terms of base unsaturation.

Our results indicate, contrary to the findings of Hissink (6), that normal soils of neutral or alkaline reaction do not contain any important amount of hydrogen as a constituent of the exchange complex. Furthermore, upon treating a neutral soil with dilute acid, such as carbonic acid, followed by leaching with water, the soil mass seems invariably to take on an acid reaction. This acid reaction is due apparently mainly to the ionization of the exchange complex which then contains hydrogen ions in the position formerly occupied by bases.

I have introduced this discussion on the question of base unsaturation primarily for the reason that we stand in danger of trying to explain too much by ion exchange in soils. The agricultural importance of base exchange is attached to a certain group of substances. Although much remains to be determined about these substances, there is strong evidence that they are salts of alumino-silicic and organic acids. The calcium salts of these acids are approximately neutral and non-hydrolyzable and have fairly definite chemical and physical properties. The calcium is substitutable by the base of other neutral salts. When the substitution is made a new set of chemical and physical properties arises depending upon the base substituted. The calcium is also replaceable by hydrogen ions with the formation of acid compounds and, therefore, compounds which combine readily with alkalies. But soils also contain various other substances, which are not involved in the ordinary base exchange reaction, which substances may react with strongly alkaline solutions. The agricultural significance of these latter substances, however, is of minor importance, at least they do not dominate the chemical and physical properties to such extent as do the more reactive base exchange compounds.

In the foregoing discussion I have endeavored to treat the phenomenon of base exchange rather broadly and with but few details. I trust that these brief remarks will suffice to introduce this symposium and that they will serve to indicate something of the general scope and importance of the subject. As those present are doubtless aware, the base-exchange phenomenon is being actively investigated and discussed by many of the leading soil investigators of Europe. In my opinion the subject is deserving of equal recognition at the hands of American agronomists.

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2. THE RELATION BETWEEN THE ELECTROKINETIC BEHAVIOR AND THE BASE EXCHANGE CAPACITY OF SOIL COLLOIDS[1]

Sante Mattson[2]

INTRODUCTION

Probably no line of investigation is more promising for throwing light on adsorption and exchange of bases by soil colloids than the study of their electrokinetic behavior. The relation between the two phenomena is at once shown by the way the nature of the adsorbed and exchangeable base affects the electrical charge of the soil particles.

The tendency to establish a difference of potential at the interface between particles and a solution is, according to the generally accepted view, dependent upon the ability of the material to adsorb, or to dissociate from its surface, ions of one sign of charge more strongly than ions of the opposite charge. This unequal distribution of ions gives rise to a Helmholtz electrical double layer;[3] for it is evident that the ion which is not adsorbed or the ion which is dissociated from the surface of the particle cannot, by virtue of electrostatic forces, diffuse very far into the solution, but must remain near the surface, forming the outer electrical layer, which of course is of an opposite sign of charge from that of the inner layer. The difference of potential between these layers is then responsible for the electrokinetic behavior of the particles.

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[1] Paper read as part of the symposium on "Base Exchange Phenomena in Soils" at the meeting of the Society held in Chicago, Ill., Nov. 17, 1925.

[2] Associate Chemist, Division of Chemical Investigations, Bureau of Soils, U. S. Department of Agriculture, Washington, D. C.

When different electrolytes are added to suspensions of soil colloids the charge of the particles is increased or decreased, depending upon the nature and concentration of the solution used. But it has been found that soil colloids of different composition differ greatly in regard to the manner in which their charge is affected by the ions of different electrolytes.

It is the object of this paper to show how differences in the electrokinetic behavior of soil colloids, as determined cataphoretically, in the presence of certain electrolytes, are related to the base exchange capacity, and how both phenomena are related to the composition of the colloid.

PREVIOUS WORK ON ACTION OF ELECTROLYTES ON ELECTRICAL BEHAVIOR OF SOIL PARTICLES

Considerable work has been done on the effect of different electrolytes on the charge of soil particles by Bradfield (4)[4], Dayhuff and Hoagland (6), Mattson (11), and others. Most of this work has been of a qualitative character. Nothing appears to have been done with the view of determining quantitative differences in the electrical behavior of different soil colloidal materials. That soil colloids differ greatly both in composition (12) and in the power to adsorb different substances (8) has lately been shown.

It has been found that in pure water and in solutions of electrolytes usually present in the soil solution the soil particles carry an electronegative charge. In regard to their effect upon the charge of the particles, the electrolytes fall into three groups, as follows: (a) Electrolytes which in low concentration increase the negative charge of the particles, including the hydroxides, the carbonates, the phosphates, the ferrocyanides, etc., of the alkali metals; (b) electrolytes which even in low concentration reduce the negative charge but do not change the sign of charge, including the common compounds of the alkaline earth metals; and (c) substances which charge the particles electropositive, including the salts of iron and aluminum, the basic dyes, and acid gelatin and other proteins.

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[3] From the principle of a constant ion product, it follows that a Donnan equilibrium must be established between the outer layer surrounding the particles, in which the ions of one sign of charge predominate over the ions of the opposite charge, and the outside solution which contains an equal number of both kind of ions.

[4] Reference by number is to "Literature Cited," p. 469.

METHODS

The colloidal soil materials used in the following experiments were prepared by the supercentrifuge method as described in previous publications. Bentonite, which is a highly colloidal material, was also included for comparison. Dr. E. V. Shannon of the National Museum kindly supplied the sample together with its analysis.[5] Table 1 shows the composition of the different materials as determined by the fusion method of the Association of Official Agricultural Chemists (3).

It will be noted that the samples cover a considerable range in chemical composition. This is more readily seen in the molecular ratio of silica to aluminum and iron oxides which varies from 0.55 to 3.82. They also cover fairly well the variations in properties that have been encountered in a large number of colloidal soil materials.

The variation in the electrical charge of these materials under different conditions was determined by observing the cataphoretic movement. The apparatus used was very similar to the one which the author has already described (11). It was designed for observing the movement of particles in the ultramicroscope and consisted essentially of a straight capillary tube terminating in two chambers containing the electrodes. The wall of the tube was ground to a thickness of 0.15 mm. at the middle to bring the interior of the tube within the focal length of the objective. The optical arrangement was of the Siedentopf-Zsigmondy type.

INFLUENCE OF EXCHANGEABLE BASE CONTENT ON ELECTRICAL NEUTRALIZATION

A relation between the electrokinetic behavior of soil colloids and their base exchange capacity can be seen in the effect of methylene blue on these materials. Methylene blue is especially suitable for bringing out differences in the electrical behavior of soil colloids, since it is capable of rendering them all isoelectric and the isoelectric point is a definite point for comparison.

[5] The analysis of the bentonite is based on the air-dry weight. The percentage composition of this material is therefore not comparable to that of the soil colloids, the analyses of which are based on the oven-dry weight.

TABLE I.—*Composition of the soil colloids selected for study.*

Kind of soil colloid	SiO_2 %	TiO_2 %	Al_2O_3 %	Fe_2O_3 %	MnO %	CaO %	MgO %	K_2O %	Na_2O %	P_2O_5 %	SO_3 %	Ignition loss %	Total %	Organic matter %	$\frac{\text{mols } SiO_2}{\text{mols } Al_2O_3+Fe_2O_3}$
Fallon loam soil, Nevada......	52.57	0.30	16.49	10.70	0.21	2.20	5.67	1.97	1.02	0.26	0.11	8.87	100.37	1.83	3.82
Sharkey clay soil, Mississippi....	52.05	0.51	22.52	8.12	0.04	1.36	2.52	1.89	0.21	0.64	0.20	9.99	100.05	3.92	3.18
Marshall silt loam soil, Nebraska.	45.93	0.48	21.72	8.94	0.07	1.19	2.01	2.28	0.21	0.46	0.21	16.47	99.97	8.55	2.82
Sassafras silt loam subsoil, Maryland.....	41.14	0.70	29.26	12.73	0.03	0.53	1.07	1.35	0.42	0.08	0.20	14.08	101.59	1.59	1.89
Norfolk fine sandy loam subsoil, N. Carolina...	39.25	0.82	33.51	11.24	0.01	0.30	0.44	0.49	0.25	0.23	0.05	14.04	100.57	1.90	1.63
Aragon clay subsoil, Costa Rica	15.86	3.54	34.38	22.67	0.07	0.21	0.29	0.27	0.33	0.26	N.D.	21.59	99.47	N.D.	0.55
Bentonite, South Dakota.......	48.80	N.D.	21.08	0.92	N.D.	1.36	4.84	N.D.	N.D.	N.D.	N.D.	20.82	97.92	—	3.81

When this dye is added in increasing amounts to the different soil colloids the negative charge of the particles is gradually reduced and finally completely neutralized as indicated by the particles ceasing to move in the electric field. A further addition of the dye charges the particles electropositive, as shown by a reversal in the direction of migration, which becomes cathodic. The different colloids require, however, very different quantities of the dye for the neutralization of their negative charge.

The cataphoresis of each colloid was measured by preparing a series of tubes in which 25 cc. of a suspension containing 10 mgms. of the colloid were mixed with 25 cc. of solutions containing increasing quantities of dye. The tubes were then allowed to stand 24 hours before the measurements were made.

The curves in Fig. 1 show the effect of methylene blue on the speed of migration of the six soil colloids and of a sample of bentonite. The ordinates represent the velocity in micron/sec. 1 volt/cm.,[6] while the abscissas represent the quantity of dye expressed in mgms. added to 10 mgms. of the soil colloid.

FIGURE 1

Each colloid has a characteristic curve, but it will be noted that all the curves are similar in form. One of the chief differences consists in the points at which the curves cross the line of zero charge. It is significant, that after a certain concentration of dye is reached, slight increases affect the charge or movement of the particles profoundly. Flocculation also becomes complete at this point.

It will now be shown that the quantities of methylene blue required to neutralize the negative charge of the different colloids is closely related to the power of the latter to adsorb and exchange bases.

Table 2 shows the milliequivalents of methylene blue required to render isoelectric 1 gm. of the various colloids and the milliequivalents of exchangeable cations present, as determined in the usual manner by treatment with neutral salt solutions. It also shows the

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[6] The results might also be expressed in terms of the electrokinetic potential, ζ, which is the potential difference of the double layer, or, as it is commonly spoken of, the "charge" on the particle. The electrokinetic potential is directly proportional to the migration velocity, v, according to the Helmholtz-Perrin formula,

$$\zeta = \frac{4\pi\eta v \, 300^2}{HD}.$$

In this formula, D is the dielectric constant of the dispersion medium, H is the potential gradient in volt/cm., η, the viscosity of the liquid, and 300^2 is a factor to convert H and ζ into absolute units. Assuming values of 80 and 0.01 for D and η, respectively, the electrokinetic potential ζ, expressed in millivolts, may be obtained by multiplying the micron/sec. velocities given in the tables by 14.1.

milliequivalents of calcium adsorbed at a hydrogen-ion concentration approximately the same as that of the methylene blue concentrations employed.[7] These two values for the base exchange capacity are given, since the capacity for adsorbing any particular cation varies considerably with the pH value, as has been shown by Bradfield (5) and by Kelley and Brown (10).

The base exchange capacity as indicated by treatment with neutral salts was determined as follows: The colloid was first saturated with calcium by leaching 1 gm. with 500 cc. of neutral $\frac{N}{1}$ $CaCl_2$. The chloride was then removed by washing. The adsorbed Ca, which is supposed to be equivalent to the cations exchanged, was displaced by a hot $\frac{N}{1}$ NH_4Cl solution, and was determined in the filtrate. The results are given in the second column of the table. The figures in the third column were obtained in a similar manner,

TABLE 2.—*The relation between base exchange capacity, methylene blue required to neutralize the charge of the colloids, and the ratio of* $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$.

Kind of soil colloid	Ca adsorbed from neutral $\frac{N}{1}$ $CaCl_2$ *Milliequiv.*	Ca adsorbed from $\frac{N}{1}$ $CaCl_2$ saturated with CO_2 *Milliequiv.*	Methylene blue required to neutralize negative charge of colloids *Milliequiv.*	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ ratio
Bentonite, Ardmore, S. Dakota	1.102	1.050	1.088	3.81
Fallon loam soil, Nevada	0.947	0.722	0.770	3.82
Sharkey clay soil, Mississippi	0.796	0.690	0.678	3.18
Marshall silt loam soil, Nebraska	0.671	0.554	0.536	2.82
Sassafras silt loam subsoil, Maryland	0.331	0.236	0.220	1.89
Norfolk fine sandy loam subsoil, N. Carolina	0.207	0.171	0.153	1.63
Aragon clay subsoil, Costa Rica	0.164	None	0.019	0.55

[7] The acidity of the methylene blue solutions varied, of course, with the quantity of dye used. One mgm. dye in 50 cc. water, which represents the mean of the concentrations used in the above experiments, gave a pH of 5.03 by the electrometric method.

but in this case both the $CaCl_2$ solution and the wash water were saturated with CO_2 and had a pH of 4.4. While, therefore, the values in column 2 (Table 2) represent the base exchange capacity at the point of neutrality, the values in column 3 show this capacity at the hydrogen-ion concentration of about pH 4.4.

It will be noted that the quantities of methylene blue required to neutralize the negative charge of the soil colloids and bentonite[8] correspond well with the quantities of exchangeable bases, but that the agreement is close only under conditions of equal pH values.

This proportionality between methylene blue values and exchangeable bases might be expected since methylene blue is apparently adsorbed by the colloids with an equivalent exchange of cations. It was found in the case of the Sharkey and Norfolk colloids that the equivalents of monovalent and divalent bases brought into solution by treatment with methylene blue were approximately equal to the equivalents of methylene blue adsorbed. The quantities of methylene blue used to render the colloids isoelectric were completely adsorbed. This was apparent from an inspection of the solution. As indicated by the dotted sections of the curves in Fig. 1, the colloids were flocculated over a considerable range on each side of the isoelectric

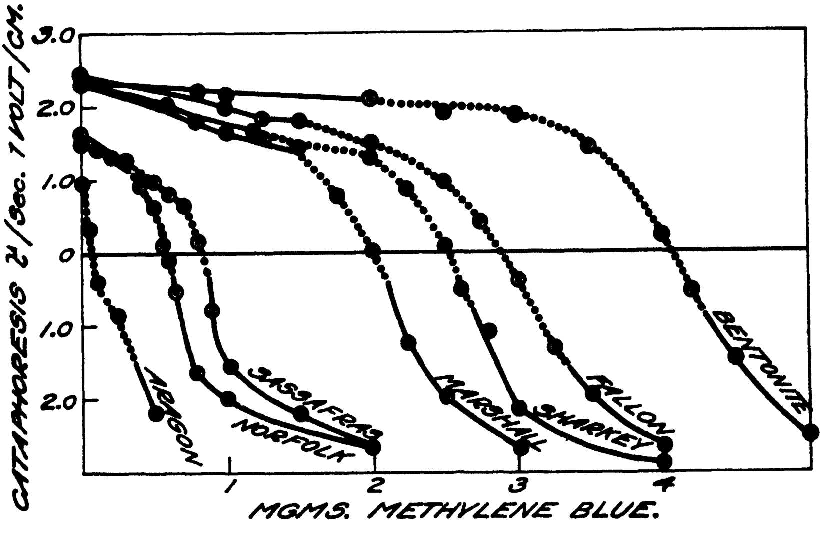

FIG. 1.—Effect of methylene blue on the electrical migration of soil colloids.

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[8] Bentonite in its electrokinetic behavior, chemical composition, and base exchange capacity is apparently similar to the colloidal soil material. A description of this material and its commercial possibilities has recently been given by Alexander (1).

point and it could be seen that no dye was left in solution. It would therefore seem that down to the isoelectric point the reaction between dye and exchangeable bases is analogous to an ordinary metathetical end reaction.

Since methylene blue exchanged with the exchangeable cations and since it was quantitatively adsorbed at the isoelectric point, it is apparent that the quantities of methylene blue shown in Table 2 removed nearly the same quantities of cations from the colloids as the $CaCl_2$ treatment. The close approximation of the two series of values shows that the colloids were not rendered isoelectric by methylene blue until practically all of the exchangeable cations were removed. It is also interesting to note that the charge of the various colloids is not much affected by the adsorption of methylene blue until most of the exchangeable bases present are replaced. This is shown by the steep sections of the curves near the isoelectric point.

It is significant that the form of the curves resembles closely the characteristic form of neutralization curves of acids obtained when the pH is plotted against the quantities of base added.

The effect of methylene blue on the charge, and the fact that the quantity of the dye required to render the colloids isoelectric is equivalent to the quantity of displaceable bases which the colloids are able to hold at the same pH, may be explained as follows: The original negative charge of the colloid is due to a partial ionization of the compounds formed with the different cations. The dissociated cations form the outer electrical layer, while the surface of the colloid is electronegative. The methylene blue cation is strongly adsorbed and displaces quantitatively the more weakly held metal cations, forming a complex which does not ionize. The negative charge of the colloids is not greatly reduced until most of the dissociating cations are displaced, when further small additions of dye produce a rapid decrease in the charge as shown by the steep section of the migration curves near the isoelectric point. At this point all the ionizable cations may be assumed to have been displaced and we have no longer an electrical double layer. But the methylene blue cation continues to be adsorbed to some extent beyond this point, and since there are no other cations to displace and to take the place of the methylene blue cation in the solution, the Cl ions of the dye must remain paired with the latter cations, forming another outer electrical layer which is electronegative while the surface layer is now electropositive.

INFLUENCE OF KIND OF EXCHANGEABLE BASE ON ELECTRICAL CHARGE

It has just been shown that one aspect of the electrical behavior of the colloids towards methylene blue appears to be governed by the quantity of exchangeable cations present. However, the charge of the colloid particles under any given conditions is determined more by the kind of exchangeable cations present than by the quantity.[9] This is, of course, evident from the data just given. The various colloids with the mixture of cations they originally contained had charges ranging between 13.4 and 33.8 millivolts in pure water, corresponding to migration velocities of 0.95 to 2.4 microns. When these cations were replaced by methylene blue all colloids had a zero potential.

A further illustration of the influence of the kind of adsorbed base on the electrokinetic behavior is shown in Fig. 2. This figure shows that varying quantities of methylene blue affected the electrical behavior of the Susquehanna colloid differently, according to whether the colloid contained exchangeable calcium or exchangeable sodium.

For this experiment a sample of Susquehanna subsoil colloid was electrodialyzed to remove all exchangeable bases. One portion of the electrodialyzed colloid was then saturated with 2 milliequivalents of NaOH and another portion with a corresponding amount of $Ca(OH)_2$. The cataphoresis of these two colloids in methylene blue was determined in the manner previously described.

FIGURE 2

The sodium saturated colloid had a markedly higher charge in pure water than the calcium colloid; also, it maintained a higher charge than the calcium colloid with additions of methylene blue up to the quantity producing electrical neutralization. It is significant that the two curves cross the line of zero potential at nearly the same point. Presumably the quantity of sodium adsorbed by the electrodialyzed colloid was equivalent to the quantity of calcium adsorbed, and the two preparations were not rendered electrically neutral until all the sodium or calcium was substituted by the methylene blue cation.

The preceding data might perhaps be more easily understood if the electrokinetic behavior of the colloids was regarded as being the expression of two factors. The magnitude of the charge might be considered as the intensity factor, and the resistance of the colloid to a change in charge—that is the buffer effect—may be looked upon as the capacity factor. This is analogous to the pH and titration value of an acid solution. In the first experiment the quantity of methylene blue required to neutralize the negative charge of the colloids is to be looked upon as a measure of the capacity factor. The last experiment shows that the intensity factor may vary considerably while the capacity remains constant.

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[9] The influence of adsorbed anions on the charge is of course not to be disregarded, but cannot be considered here.

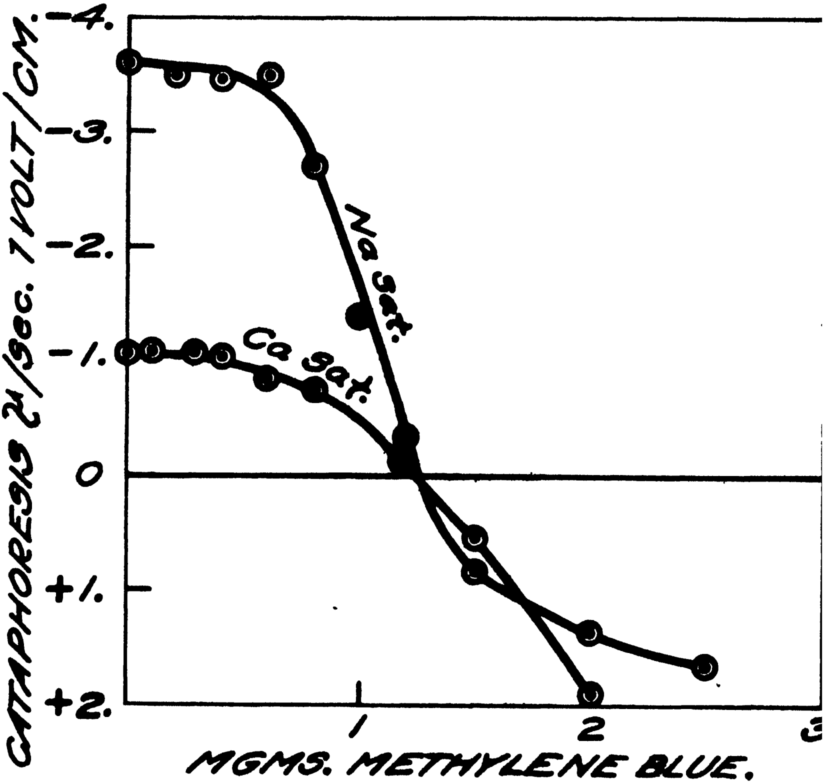

FIG. 2.—Effect of methylene blue on the electrical migration of a soil colloid saturated with Na and Ca.

RELATION OF ELECTROKINETIC BEHAVIOR AND BASE EXCHANGE CAPACITY TO RATIO OF $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$

In previous papers (2,9) it was shown that several properties of the colloids vary approximately as the $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ ratios, and further details will be given in a forthcoming publication by Anderson and Mattson. This relationship reappears in connection with the electrokinetic behavior and the base exchange capacity of the colloids.

It can be seen by referring to Table 2 that the quantities of methylene blue required to render the colloids isoelectric and the quantities of exchangeable bases are both related to the ratio of silica to iron and aluminum oxides. This relationship is shown graphically in Fig. 3 in which the ordinates represent the milliequivalents of calcium and of methylene blue as given in columns 3 and 4 of Table 2, while the abscissas represent the ratio of silica to iron and aluminum oxides.

FIGURE 3

It can be seen that there is a fairly high degree of correlation between the two series of values.

In the previous pages it was shown that the electrokinetic behavior of the colloids under certain conditions seems to be governed directly

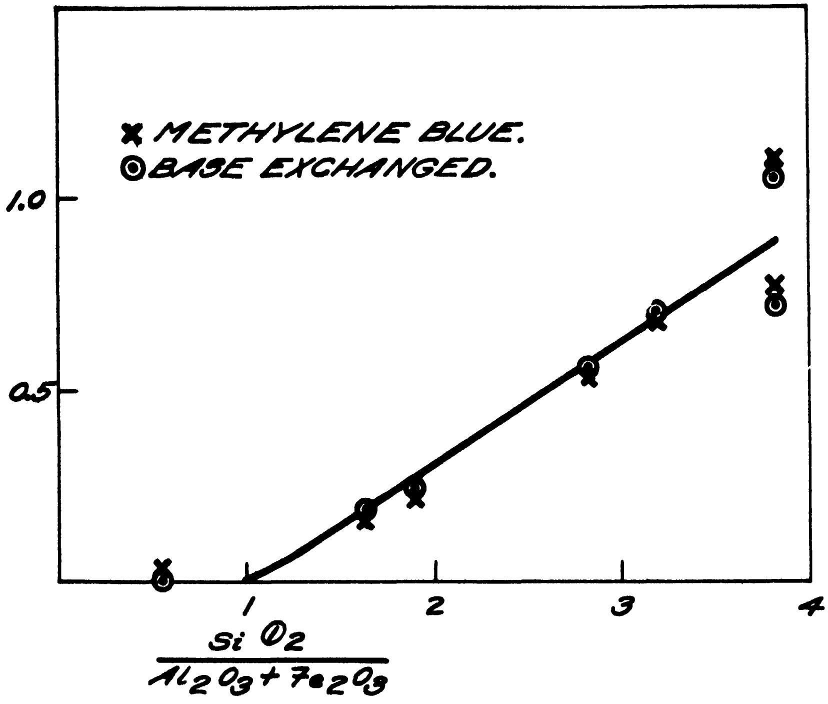

FIG. 3.—Relation between $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$, base exchange capacity, and methylene blue required to render the soil colloids isoelectric.

by the exchangeable bases. Mattson (11), Gedroiz (7), and Kelley and Brown (10) have found that a similar close relationship exists between swelling or dispersability of the soil and exchangeable bases. The correspondence between electrokinetic behavior and silica ratio, however, is evidently not accidental. Very probably the silica ratio governs the electrokinetic behavior, exchangeable bases, and other properties of the colloids within certain limits. Some data have already been obtained indicating this. It should be borne in mind, however, that the $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ ratio takes into account only the major constituents of the colloid. Other materials are also present and these undoubtedly are of some importance in determining the colloidal behavior.

SUMMARY

A relationship is shown to exist between the electrokinetic behavior, the base exchange capacity, and the composition of soil colloids.

The quantities of methylene blue required to neutralize the negative charge of different soil colloids correspond closely to the total contents of exchangeable bases.

The charge on the soil colloids varies markedly according to the kind of exchangeable base present. When a given colloid is saturated with sodium the charge is much higher than when saturated with calcium. When the exchangeable bases are replaced by the methylene blue cation the colloids become isoelectric.

The contents of exchangeable bases and the quantities of methylene blue required to neutralize the negative charge of the various soil colloids parallel the $\frac{SiO_2}{Al_2O_3+Fe_2O_3}$ ratios.

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3. BASE EXCHANGE IN SOIL COLLOIDS AND THE AVAILABILITY OF EXCHANGEABLE CALCIUM IN DIFFERENT SOILS[1]

F. W. PARKER AND W. W. PATE[2]

Soils vary widely in their content of exchangeable bases and this variation cannot be explained solely on the basis of variations in the texture or colloid content of the soil. We may have two soils of the same colloid content and one may contain several times as much exchangeable base as the other. Two explanations may be advanced to explain this fact. First, we may assume that some of the noncolloidal matter in a soil contains exchangeable base. If that is the case the exchangeable base content of the soil would not be directly proportional to the colloid content. Second, we may assume that exchangeable bases are found only in the colloidal material but that colloids from different soils contain different amounts of exchangeable base. A study of the results of other investigators indicates that the second explanation is probably more nearly correct than the first.

Kelley and Brown (16)[3] have shown that the colloidal portion of a soil contains much more exchangeable base than that portion of the soil that would not pass a 100-mesh screen. Their results with clay from these soils indicate that the colloid from different soils may contain different amounts of exchangeable base. Anderson, et al (3) have shown that the adsorption of water by soil is due, almost entirely, to the soil colloids. The results of Bouyoucos (5) and Anderson (2) indicate that the heat of wetting of a soil is due to the presence of the colloidal material and is not influenced by the non-colloidal soil constituents. They found that the heat of wetting of the colloid from different soils varied considerably. It is apparent from these studies that several soil properties are due almost exclusively to the colloidal portion of the soil, and that the properties of colloid from different soils may differ considerably. If that can be shown to be true for the property of base exchange, it may serve as an explanation for the lack of correlation between the amount of exchangeable base in a soil and its colloid content.

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[1] Paper read as a part of the symposium on "Base Exchange Phenomena in Soils" at the meeting of the Society held in Chicago, Illinois, November 17, 1925. Published with the permission of the Director of the Alabama Agricultural Experiment Station.

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[3] Reference by number is to "Literature Cited," p. 481.

The present investigation was undertaken to determine (a) what portion of the exchangeable bases is in the colloidal material of the soil, (b) whether or not there is a correlation between the chemical composition of the soil colloid and its content of exchangeable base, (c) the influence of the nature of the exchangeable base on some of the properties of a soil, and (d) the availability of the exchangeable calcium in different soils. Fourteen soils were used in the investigation. The soils came from Alabama, Illinois, Michigan, and Ohio. All soils were from the plowed zone and they varied widely in texture, reaction, origin, and content of organic matter.

METHOD

The colloidal material was extracted from the soil by a procedure similar to that of Bradfield (6) and of Gile, et al (8). The soil was churned in a barrel churn and the suspension allowed to stand until most of the coarse material had settled out. The suspension was then passed through a super-centrifuge at the rate of 19 liters per hour. The centrifuge was geared down to make 15,000 revolutions of the bowl per minute. The material passing through the centrifuge under those conditions was considered colloidal. The soil colloid was then thrown out of suspension by passing through the super-centrifuge at the rate of 7 liters per hour when the super-centrifuge was making 30,000 revolutions per minute.

In some cases the soil was divided into three separates and the different separates were studied. The first separate, S_1, was that portion of the soil that settled out from a 12-inch column of the soil suspension in one hour. The second separate, S_2, was that portion that did not settle out in one hour but was thrown out of suspension when passed through the centrifuge the first time, at the low rate of speed. The third separate was the colloidal material.

The content of total exchangeable bases in the soil or colloid was determined by the method of Kelley and Brown (16). The soil or colloid was saturated with NH_4. The excess of NH_4Cl was removed and the exchangeable NH_4 determined by distillation with MgO.

The colloid content of the soils was determined by the water absorption method of Gile, et al (8). The heat of wetting of soils and colloids was determined by a method similar to that of Bouyoucos (5).

BASE EXCHANGE IN COLLOIDAL AND NON-COLLOIDAL SOIL CONSTITUENTS

The first experiments were planned to determine whether or not the exchangeable bases are found solely in the colloid fraction of the soil. The fact that non-colloidal soil constituents do not adsorb water or evolve heat on wetting has formed the basis of two methods of determining the colloid content of soils, namely, the ratio method using water adsorption data and the ratio method using heat of wetting data. If the exchangeable bases are found exclusively in the colloidal material, the colloid content of the soil could be determined by the ratio method using exchangeable base data. The ratio $\frac{\text{mgm. eq. exchangeable base in soil}}{\text{mgm. eq. exchangeable base in colloid}} \times 100$ should give the percentage colloid in the soil. The method should give results in good agreement with those obtained from water absorption or heat of wetting data. If the non-colloidal constituents contain replaceable base it would be impossible to calculate the colloid content of a soil from exchangeable base data. In that case the results obtained would always be too high.

In order to determine whether or not the colloid content of the soil calculated from exchangeable base data agrees with the results obtained from water adsorption data, 14 soils were studied. The colloid content of each soil was determined by the three methods. The results are given in Table 1. The second and third column of the table give the data from which the colloid content given in the fourth column was calculated. The last three columns of the table give the colloid content of the soil as determined by the three methods. The table shows in nearly all soils an excellent correlation between the results obtained by the three methods, indicating that the exchangeable bases in a soil are found entirely in the colloidal material.

TABLE 1.—*The colloid content of soils as determined by the ratio method using data for exchangeable base, water absorption, and heat of wetting.*

No.	Soil	Exchangeable base Colloid	Exchangeable base Soil	Colloid content by ratio method Replaceable base	Colloid content by ratio method Water absorption	Colloid content by ratio method Heat of wetting
		mgm. eq.	*mgm. eq.*	%	%	%
1.	Orangeburg sandy loam	8.09	0.51	6.3	5.8	7.4
2.	Cecil clay	8.52	2.75	32.3	32.4	47.1
3.	Greenville sandy loam	9.30	1.30	14.0	14.4	19.5
4.	Holston silt loam	10.65	2.84	26.6	17.2	33.5
5.	DeKalb fine sandy loam	12.75	0.70	5.5	6.1	6.1
6.	Clarksville silt loam	18.32	2.74	15.0	10.6	12.4
7.	Hollywood clay	38.17	19.90	52.1	28.5	51.7
8.	Wooster silt loam	23.43	5.78	24.7	21.4	26.8
9.	Susquehanna clay	47.22	30.95	65.5	55.5	55.6
10.	Saginaw clay	42.04	16.00	38.1	34.6	40.5
11.	Michigan silt loam	24.99	9.73	38.8	31.3	38.8
12.	Gray silt loam	23.15	4.20	18.1	27.6	17.7
13.	Black clay loam	52.75	20.51	38.9	37.2	36.0
14.	Oktibbeha clay	50.20	37.36	74.4	87.7	72.2

While the correlation of results is in general very good there are four instances in which one of the three methods gives a result considerably different than that obtained by the other two methods. The heat of wetting method gives a high result for Cecil clay. The water adsorption method gives a low result with Holston silt loam and Hollywood clay, and it gives a high result for the gray silt loam. The cause of these differences is unknown. However, it should be noticed that there is usually a closer agreement between the results of the exchangeable base method and the heat of wetting method than between the results obtained by the water absorption method and results obtained by either of the other two methods.

A study of the relation between the colloid content of soil separates and their content of total exchangeable base gives further proof that the exchangeable bases are found only in the colloidal fraction of the soil. Three separates were made on each of five soils. The content of exchangeable bases was determined in each separate and the colloid content of each separate was determined by the water absorption method. The results are given in Table 2.

The first separate, S_1, from all soils was very low in exchangeable base and very low in colloid, indicating that the non-colloidal material did not contain bases in an exchangeable condition. The second separate, S_2, in four of the five soils, contained approximately one-half as much exchangeable base as did the colloid but the colloid content of this separate was approximately 50%. In every case there is an excellent agreement between the relative amount of exchangeable base in the separates and their colloid content. Similar results were secured when the colloid content was calculated from heat of wetting data.

Apparently the three properties of soils, adsorption of water, evolution of heat of wetting, and the ability to exchange bases is due to the presence of soil colloids and is not a property of the non-colloidal soil constituents.

TABLE 2.—*Relative amounts of exchangeable base and colloid in soils and their separates.*

No.	Soil	Relative amount of exchangeable base				Relative amount of colloid[a]			
		Soil	S_1	S_2	Colloid	Soil	S_1	S_2	Colloid
2.	Cecil clay	31.5	3.8	53.2	100	32.4	5.0	47.8	100
8.	Wooster silt loam	25.4	8.2	40.7	100	21.4	8.4	36.1	100
10.	Saginaw clay	35.1	6.0	57.9	100	34.6	8.8	54.7	100
11.	Michigan silt loam	37.5	5.6	17.0	100	31.3	6.0	20.7	100
13.	Black clay loam	36.3	10.5	62.3	100	37.2	12.2	64.7	100

[a] The colloid content of the soil and separates was determined by the water absorption method.

RELATION BETWEEN CHEMICAL COMPOSITION OF SOIL COLLOID AND CONTENT OF EXCHANGEABLE BASE

The data in Tables 1 and 2 show that the differences in the exchangeable base content of soils of the same colloid content cannot be explained by attributing some of the exchangeable base to the non-colloidal constituents of the soil. The data in the third column of Table 1 show that it is due to the fact that colloids from different soils contain different amounts of exchangeable base. The colloid from Oktibbeha clay contains more than six times as much exchangeable base as the colloid from Orangeburg sandy loam. Cecil clay soil contains about one-sixth as much exchangeable base as the black clay loam and the colloid content of the two soils is very similar. However, the colloid from the black clay loam contains approximately six times as much exchangeable base as the colloid from Cecil clay. These differences are similar to differences observed in respect to other properties, namely, heat of wetting (2, 4) and the absorptive capacity for dye and ammonia (8). Such differences are probably due to some fundamental difference in the nature of the colloid from the various soils.

Several investigators (10, 13, 1, 18) have noted that a relation exists between the chemical composition of soil colloids and some of their properties. The best correlation was found between the SiO_2/

Al_2O_3 ratio or the SiO_2/R_2O_3 ratio and the properties of the colloid. In order to determine whether there was a correlation between the chemical composition and content of exchangeable bases, the colloid from all soils was analyzed and the SiO_2/R_2O_3 ratio calculated. The analysis was carried out by the procedure of Hillebrand (12). TiO_2 was not determined and is included in the Al_2O_3. This makes the recorded SiO_2/R_2O_3 ratio a little low, but the error is not large.

Table 3 gives the SiO_2/R_2O_3 ratio of the soil colloids, their content of replaceable base, and their heat of wetting. The soil colloids are arranged in the order of their SiO_2/R_2O_3 ratio. The ratio varies from 1.17 in the Orangeburg colloid to 3.31 in the Oktibbeha colloid. The content of exchangeable base varies from 8.09 mgm. eq. in Orangeburg colloid to 52.75 mgm. eq. in colloid from black clay loam, while the heat of wetting varies from 3.94 calories for Cecil colloid to 16.10 calories for the colloid from the black clay loam. In general, there is an excellent correlation between the SiO_2/R_2O_3 ratio and the content of exchangeable base and heat of wetting. Colloids 7 and 9 contain more exchangeable base and have a higher heat of wetting than one would expect from their SiO_2/R_2O_3 ratio. Colloids 11 and 12 contain less exchangeable base and have a lower heat of wetting than would be expected. The lack of correlation between the value of the SiO_2/R_2O_3 ratio and the properties of the colloids in the instances just mentioned cannot be explained. It is not due to differences in content of organic matter, for the colloid from soil 9 is very low in organic matter, while the colloid from soil 7 is high in organic matter and

TABLE 3.—*The SiO_2/R_2O_3 ratio of soil colloid, the exchangeable base content, and heat of wetting of the colloid.*

No.	Soil colloid	Ratio SiO_2/R_2O_3	Exchangeable base *mgm. eq.*	Heat of wetting per gram *calories*
1.	Orangeburg sandy loam	1.17	8.09	4.05
2.	Cecil clay	1.30	8.52	3.94
3.	Greenville sandy loam	1.33	9.30	4.98
4.	Holston silt loam	1.69	10.65	4.81
5.	DeKalb fine sandy loam	1.85	12.75	6.23
6.	Clarksville silt loam	1.93	18.32	8.30
7.	Hollywood clay	2.09	38.17	11.77
8.	Wooster silt loam	2.24	23.43	8.52
9.	Susquehanna clay	2.46	47.22	14.51
10.	Saginaw clay	2.58	42.04	12.30
11.	Michigan silt loam	2.61	24.99	9.54
12.	Gray silt loam	2.78	23.15	9.03
13.	Black clay loam	2.91	50.20	16.10
14.	Oktibbeha clay	3.31	52.75	10.89

both show differences of the same order. The correlation between the heat of wetting and the content of exchangeable base is better than between either of those properties and the ratio of SiO_2 to R_2O_3. The exchangeable base content of a soil colloid may be a better index of its properties than the ratio of SiO_2 to R_2O_3.

The relation existing between the SiO_2/R_2O_3 ratio of soil colloids and their properties is of fundamental importance in soil investigations. This relation has been recognized by several investigators. Hardy (10, 11), in studying the shrinkage coefficient and certain moisture relations of clays and soils, has recognized the relation between the chemical composition of the soil colloid and some of its properties. The SiO_2/R_2O_3 ratio of the clay fraction of his soils varied from 1.99 to 4.23. Joseph and Handcock (13) have studied the relationship between the chemical composition and some of the properties of clay. They found a close correlation between the SiO_2/R_2O_3 ratio of the clay and its plasticity and moisture equivalent. Their results also show a relation between the silica-alumina ratio and some chemical properties of the clay. Joseph (14, 15) has continued this study and, using data from publications of the Bureau of Soils (8, 2, 17, 19), has shown the relation between chemical composition of the colloid, its heat of wetting, binding power, tensile strength, and absorption of water

Gile (9), in discussing the investigation of the Bureau of Soils, states that there is apparently an interrelation of the properties of the soil colloids and that the physical properties of the colloid correlate fairly well with its chemical composition. Anderson and Mattson (1) in a study of the data from earlier publications of the Bureau of Soils have clearly shown the relation between the SiO_2/R_2O_3 ratio of the colloids, their heat of wetting, and the absorption of ammonia gas. They indicate that a similar correlation exists between the SiO_2/R_2O_3 ratio and other properties. Pate (18), also using data from the publications of the Bureau of Soils, has shown the correlations mentioned. These studies, particularly the results of the Bureau of Soils together with the results presented in Table 3, seem to establish firmly the relationship between the SiO_2/R_2O_3 ratio of soil colloids and many of their physical and chemical properties, including their content of exchangeable base From the limited data presented in Table 3 it seems possible that the content of total exchangeable base may correlate with other properties more closely than the SiO_2/R_2O_3 ratio. A large amount of additional data would be necessary to prove or disprove that fact. It is evident, however, that from a knowledge of the exchangeable base content of soil colloids one could usually predict the properties of the colloid.

INFLUENCE OF NATURE OF EXCHANGEABLE BASE ON SOIL PROPERTIES

Having established the importance of the total content of exchangeable base in soil colloids, it is important that the influence of the nature of the replaceable base be considered. If that is determined, then knowing both the amount and nature of the replaceable base one could, with considerable confidence, predict the properties of the colloid or soil.

Gedroiz (7) has shown that the physical properties of a soil depend in large measure upon the nature of the exchangeable base. Soils saturated with the monovalent bases, especially sodium, are defloculated, remain in suspension almost indefinitely, and are in a very poor physical condition. Soils saturated with the divalent bases, especially calcium, have a good physical condition, are floculated, and readily settle out of suspension. Pate (18) has shown that the nature of the exchangeable base has a decided influence on the heat of wetting of soils and soil colloids. Table 4 gives a portion of his heat of wetting data together with water absorption data for the same soils.

TABLE 4.—*Relative heat of wetting and water absorption by soil saturated with different bases.*

Base	Oktibbeha clay		Hollywood clay	
	Heat of wetting	Water absorption	Heat of wetting	Water absorption
Na	69.6	136.0	81.8	120.0
K	53.7	88.5	60.0	77.3
NH_4	62.2	74.8	61.7	68.5
Ba	89.8	103.7	90.8	85.0
Ca	95.0	106.0	108.5	105.0
Mg	95.4	103.2	109.7	101.0
Untreated soil	100.0	100.0	100.0	100.0

For sake of comparison, the data are presented on a relative basis, the untreated soil being given a value of 100. These soils had been saturated with the different bases by leaching with N/1 solutions of their chlorides and then washing with water to remove the excess of salt. Saturation with monovalent bases caused a considerable reduction in the heat of wetting of both soils. Saturation with barium caused a small reduction in the heat of wetting, but the other divalent bases had very little influence on the heat of wetting. The results with water absorption are similar to those obtained with heat of wetting, except that saturation with sodium caused a large increase in the water absorptive capacity of the soil instead of a decrease. The other monovalent bases lowered the absorptive capacity of the soil, while the divalent bases usually slightly increased the amount of water absorbed. These differences show that the nature as well as the amount of exchangeable base have a decided influence on the properties of the soil or soil colloid. Studies similar to the above may be of value in determining the nature of the reactions, physical or chemical, that are involved in the absorption of water by a soil and the evolution of heat when a soil is moistened. Why should saturating a soil with the potassium or ammonium ion reduce the heat of wetting 40% and reduce water absorption 25%? Why should saturating the soil with the sodium ion reduce the heat of wetting and increase water absorption? The authors have no explanation for these differences but such studies may be of value in solving some of the fundamental problems of soil behavior.

AVAILABILITY OF EXCHANGEABLE CALCIUM IN DIFFERENT SOILS

After considering the influence of the nature of the replaceable base on soil properties it seemed desirable to study the ease of replacement or availability of the exchangeable calcium in different soils. Calcium was studied because it is present in relatively large amounts and because its ease of replacement might be related to the plant's response to lime. The availability of the exchangeable calcium has not been carefully studied. Robinson and Williams (20) made some studies using a N/25 CO_2 solution as a solvent to determine available calcium. That method seems rather arbitrary and unsatisfactory, although it has been useful in certain lines of work. However, there is need for a more accurate method of estimating the availability of exchangeable calcium or any other base in an exchangeable form. It seems that such a method could be based on the competition of equivalent quantities of base for the "absorbing complex" of the soil Truog (22) has used this principle, the competition of equivalent amounts of acid for a base, in studying the avidity of soil acids. In his method equal quantities of soil acid and acetic acid compete for the base potassium. The distribution of the base between the acids is determined by titration.

Using Truog's method, Tidmore and Parker (21) have shown that the results correlate well with the results of other methods of measuring the strength or avidity of soil acids, namely, H-ion concentration and the ability of the soil to catalyze the inversion of cane sugar. In the proposed method for estimating the availability of exchangeable calcium equal quantities of exchangeable calcium and potassium in potassium acetate compete for the absorbing complex of the soil. After the system comes to equilibrium the distribution of the calcium is determined. The procedure used follows:

The exchangeable calcium content of the soil is determined by leaching 25 grams of soil with 1,000 cc. of N/1 NH_4Cl. 100 grams of soil are then treated with 300 cc. of a potassium acetate solution containing an amount of potassium equivalent to the exchangeable calcium in the soil. This is conveniently done by taking as many cubic centimeters of N/1 acetate as there are milligram equivalents of calcium in the soil. The soil and the acetate solution are shaken for 30 minutes, filtered, and calcium determined in the filtrate. At the same time water soluble calcium is determined in an extract using 100 grams of soil and 300 cc. of water. The water soluble calcium is subtracted from the calcium in the potassium acetate filtrate to give the calcium replaced by the potassium. The percentage of the total calcium replaced is calculated. The greater the percentage replaced by potassium the greater the availability of the exchangeable calcium.

The method was used on nine soils and the results, together with the total exchangeable base content and H-ion concentration of the soils, are given in Table 5.

The soils are arranged in the order of the availability of their exchangeable calcium. In the first three soils the content of exchangeable calcium is apparently greater than the content of total replaceable base determined by the method of Kelly and Brown. This is doubtless due to the solubility of non-exchangeable calcium in N/1 NH_4Cl. Consequently, in determining the availability of calcium in those soils, the assumption was made that all the exchangeable base was calcium and an amount of potassium acetate equivalent to the total base was used instead of an amount equivalent to the apparent exchangeable calcium content.

The data in the fourth and fifth columns of the table show the great variation in the availability of the exchange calcium. This indicates that either an exchange of ions did not take place to the same extent in all soils or that some ion other than calcium came into solution. The soils having calcium of low availability were partially desaturated, as shown in columns 2 and 3, and had a high concentration of H ions. It seems probable, therefore, that the low availability of the calcium in the acid soils is due to the presence of hydrogen in an exchangeable condition and that it is more available, more easily replaced, than the calcium. In general the greater the strength of the soil acids as indicated by the H-ion concentration, the lower the availability of the calcium. The one outstanding exception to this statement was the result obtained with Cecil clay. Just how important the availability of the exchangeable caclium is with respect to the response of plants to lime has not been determined. It is probable that it is of considerable importance and that the proposed method will be of some value in studying the availability of soil calcium to plants.

TABLE 5.—*The exchangeable calcium content of soils, its availability as measured by the potassium acetate method, and the H-ion concentration of the soils.*

Soil	Total exchangeable base	Exchangeable calcium	Percentage exchangeable calcium available	Relative availability of exchangeable calcium	H-ion concentration, pH
	mgm. eq.	*mgm. eq.*			
Hollywood clay	19.90	27.34[a]	48.14[b]	100	6.55
Michigan silt loam	9.73	25.05[a]	41.41[b]	86	7.60
Saginaw clay	16.00	21.15[a]	34.18[b]	71	6.60
Black clay loam	20.51	19.36	21.02	44	5.00
Oktibbeha clay	37.36	21.76	19.21	40	5.05
Wooster silt loam	5.78	4.06	19.21	40	5.00
Cecil clay	2.75	2.61	17.24	36	5.80
Gray silt loam	4.20	1.04	5.77	12	4.35
Susquehanna clay	30.95	8.77	4.67	10	4.70

[a] Result for exchangeable calcium high, due to the solubility of non-exchangeable calcium in N/1 NH_4Cl.

[b] In determining the availability the amount of potassium acetate used was equivalent to the total exchangeable base content of the soil.

The method suggested for determining the availability of the exchangeable calcium can be adapted to the study of the availability of any exchangeable base. The results of Tidmore and Parker (21) show that it is well adapted to the study of the ease of replacement of H ions.

The availability of the exchangeable bases in a soil may not have an important influence on the physical properties of a soil, but it is probable that it is of importance in the nutrition of plants.

SUMMARY

The experiments presented in this paper were undertaken for the purpose of determining: (a) The exchangeable base content of the colloidal and non-colloidal soil constituents, (b) the relation between the chemical composition of soil colloids and their content of exchangeable base, (c) the influence of the nature of the exchangeable base on soil properties, and (d) the availability of exchangeable calcium in different soils. The results obtained may be summarized as follows.

1. As far as the accuracy of the methods used can determine, all of the exchangeable base in a soil is in the colloidal material.

2. The colloid content of a soil can be determined by the ratio method using base exchange data.

3. There is a good correlation between the SiO_2/R_2O_3 ratio of soil colloids and their content of exchangeable base. Colloids having a high ratio are high in exchangeable base.

4. The nature of the exchangeable base influences the heat of wetting and absorption of water by the soil. Soils saturated with monavalent bases have a lower heat of wetting and, with the exception of sodium, absorb less water than soils saturated with divalent bases.

5. A method is proposed for determining the availability of exchangeable calcium, or other bases, in the soil.

6. The exchangeable calcium in soils having a high H-ion concentration has a low availability. The availability of calcium in non-acid soils is high.

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4. RECIPROCAL REPRESSION BY CALCIC AND MAGNESIC ADDITIONS IN SURFACE SOIL[1]

W. H. MACINTIRE[2]

In a brief symposium contribution it is not permissible to give the extensive bibliography on interchange of bases. Suffice it to say that the classic contributions of Hissink, Gedroiz, and Kelley, in particular, have emphasized the importance of the subject. These studies have demonstrated the far-reaching effect of the phenomena and they have been most informative in accounting for the genesis of alkali soils. But, in dealing with humid soils, we face the difficulty of a rational interpretation of those interchange phenomena which may be demonstrated by the imposition of extreme conditions in laboratory studies. For, under humid conditions, the frequent leaching of soluble salts vitiates the influence of mass action and shifts equilibria in the surface soil, so that basic exchange may not only be precluded but actually superseded by "*reciprocal repression*" between added calcium and native magnesium, or between added magnesium and native calcium. However, a different condition may obtain when we consider the subsoil in its natural placement with the surface soil.

Liming involves the usage of the relatively insoluble oxide, hydrate or carbonate forms of calcium and magnesium, which are partly or completely absorbed and then subjected to progressive diminution through removal as soluble salts. Therefore, it would seem that lysimeter investigations not only afford a dependable means of determining interchange, or antithetic reactions, and differential properties of soil and subsoil, but they also constitute probably our nearest approach to practice. This contribution is based upon this viewpoint and will be devoted exclusively to lysimeter data.

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EXPERIMENTAL

The present paper will offer findings obtained during a period of 12 years from soil and soil-subsoil lysimeter studies where the range of treatment has extended between a minimum of 250 pounds and a maximum of 200,000 pounds of CaO, or the MgO equivalent, per 2,000,000 pounds of soil. The soils studied were rock-derived, formed *in situ*, of moderate fertility and of acid reaction. The red clay subsoil was that natural to the two surface soils. The Ca and Mg additions were based on chemical equivalence and all leaching results are expressed in terms of $CaCO_3$ per 2,000,000 pounds of soil.

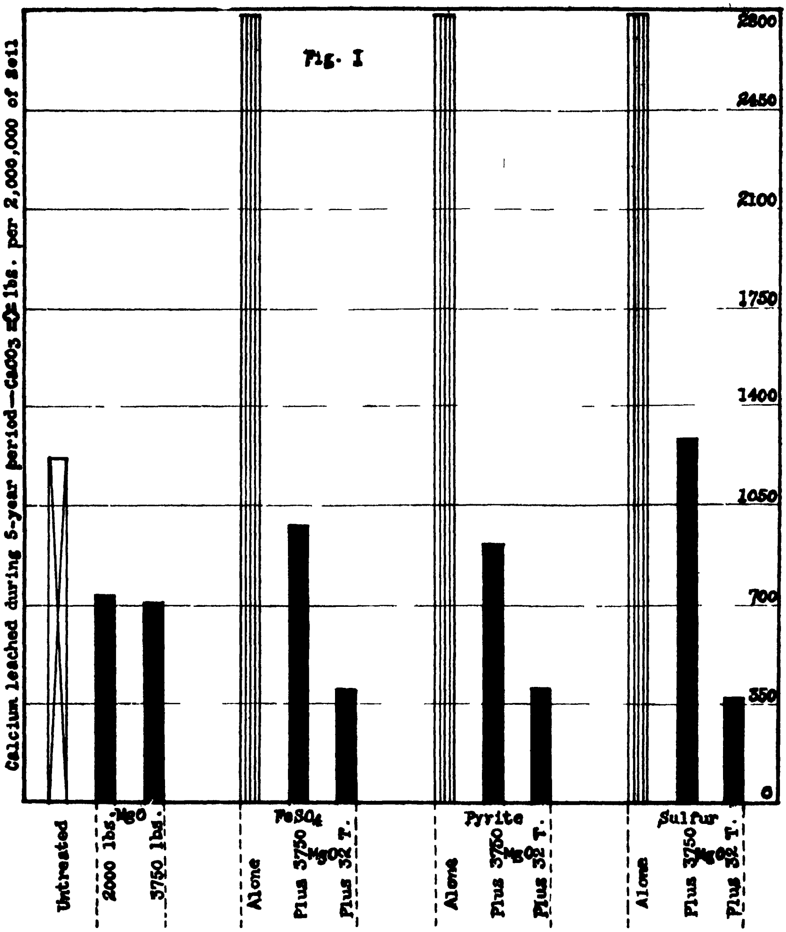
FIVE-YEAR LYSIMETER STUDIES WITH SURFACE SOIL

Repression of calcium by magnesium.—The data of Table 1 and the comparisons of Fig. 1 show the influence of 2,000-pound, 3,750-pound, and 32-ton MgO additions upon annual and total leachings of calcium derived from an average annual precipitation of 51 inches for a five-year period. Sulfur was also used as a supplement in soluble and in oxidizable forms at the constant rate of 1,000 pounds

TABLE 1.—*Calcium outgo from an acid loam over a 5-year period as influenced by additions of MgO, with and without sulfur supplements.*

Treatment		$CaCO_3$ equivalent per 2,000,000 lbs. of soil								
		Annual periods					5-year period			
MgO	Sulfur	1	2	3	4	5	Total	Average annual	Over control	Over group control
None	None	291	248	234	260	188	1,221	244	——	——
2,000 lbs.	None	155	147	166	161	111	740	148	— 481	——
3,750 lbs.	None	147	143	166	160	96	712	142	— 509	——
None	$FeSO_4$	1,348	611	374	278	173	2,784	557	+1,563	——
3,750 lbs.	$FeSO_4$	579	139	121	101	89	1,029	206	— 192	—1,755
32 tons	$FeSO_4$	82	60	103	94	60	399	80	— 822	—2,385
None	Pyrite	585	896	615	381	308	2,785	557	+1,564	——
3,750 lbs.	Pyrite	297	242	166	159	48	912	182	— 309	—1,673
32 tons	Pyrite	99	69	88	92	56	404	81	— 817	—2,381
None	Sulfur	1,279	617	400	306	186	2,788	558	+1,567	——
3,750 lbs.	Sulfur	526	209	245	189	119	1,288	258	+ 67	—1,500
32 tons	Sulfur	55	65	90	104	59	373	75	— 848	—2,415

of S per 2,000,000 pounds of soil. The 3,750-pound alkali-earth additions represent treatments of 2,000 pounds of CaO, or its equivalent, plus 1,750 pounds to care for the immediate acidity of the ferrous sulfate and the potential acidity of pyrite and flowers of sulfur.



Magnesia alone.—Both the 2,000-pound and the 3,750-pound unsupplemented MgO additions materially repressed the calcium outgo for each annual period. The total repression for the five-year period amounted to approximately 500 pounds in each case. After the first year this repressive effect was due to the hydrolysis of MgO which had been absorbed by the soil.

Magnesia plus sulfur.—The calcium outgo from the $FeSO_4$ control (accounted for in most part as $CaSO_4$) was materially greater than that from the no-treatment control for the first three years and especially so during the initial year (3, 6).[3] But the smaller MgO addition greatly reduced the solvent action of the soluble iron sulfate upon native calcium combinations during the first year. Consistently thereafter this MgO–$FeSO_4$ treatment gave a calcium outgo not only less than that from the $FeSO_4$ control, but also less than that from the no-treatment control so that its five-year calcium yield was 192 pounds less than that from the untreated soil.

The 32-ton MgO addition still further repressed the replacement activity of the sulfate radical derived from $FeSO_4$, so that each annual calcium outgo from the heavy MgO addition plus $FeSO_4$ was only about one-third that of the corresponding one from the no-treatment control. The totals of these annual repressions amounted to 822 pounds and 2,385 pounds, in respective comparisons with the no-treatment and $FeSO_4$ controls. The large excess of MgO served to protect the native calcium complexes from the SO_4 radical of the $FeSO_4$ addition, and the large amount of $MgSO_4$ present was inactive upon the native calcium complexes—as such protection and inactivity were measured by production of soluble calcium salts—in the presence of the excess of MgO, $Mg(OH)_2$, $MgCO_3$, and absorbed magnesium.

Varying periodic excesses of the SO_4 radical came out from the pyrite group as a result of the oxidative processes which reached their peak during the second year(4). Yet, under these conditions the light MgO addition gave no increase in calcium outgo over the no-treatment control during the first two years, whereas thereafter a definite repression was registered. Again, with the 32-ton MgO addition with pyrite, a still more marked repression resulted in five annual leachings of distinctly less calcium-salts concentration than the corresponding ones from the no-treatment control.

In the elementary sulfur group the same general relations hold as for the $FeSO_4$ treatments, except that the positive repressive action was delayed until the third year in the lighter treatment, resulting in the single plus quantity as a five-year total.

The close agreement between the repressions of 822 pounds, 817 pounds, and 848 pounds below the outgo from the no-treatment control and the corresponding depressions of 2,385 pounds, 2,381 pounds, and 2,415 pounds below the yields from the group controls from the heavy MgO-treatment with $FeSO_4$, pyrite, and elementary sulfur, respectively, merits observations relative to the factor of added and oxidized sulfates. During the first year the removals of SO_4 from the three forms of sulfur additions were practically 100%,

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[3] Reference by number is to "Literature Cited," p. 496.

40%, and 15%, respectively (4). Thereafter, the heavy MgO continued its accelerative influence upon sulfate outgo and repression of calcium where used in combination with $FeSO_4$, all of which had been leached during the first year. The 32-ton MgO addition showed a still greater acceleration upon outgo of sulfates from the sulfur supplement during the second year; but it was distinctly depressive upon the oxidation of the pyrite and losses of sulfates therefrom (4). Yet, in spite of these differences, as to periodic variations in concentrations of soluble $MgSO_4$, the excessive MgO additions exerted the same ultimate influence upon sulfate outgo and repression of calcium leachings for the five-year period. It is thus apparent that a heavy concentration of $MgSO_4$ for a short period and lesser concentrations of $MgSO_4$ maintined for a protracted period caused no interchange of calcium when excessive amounts of MgO and its hydrate, carbonate, and silicate derivatives were also present.

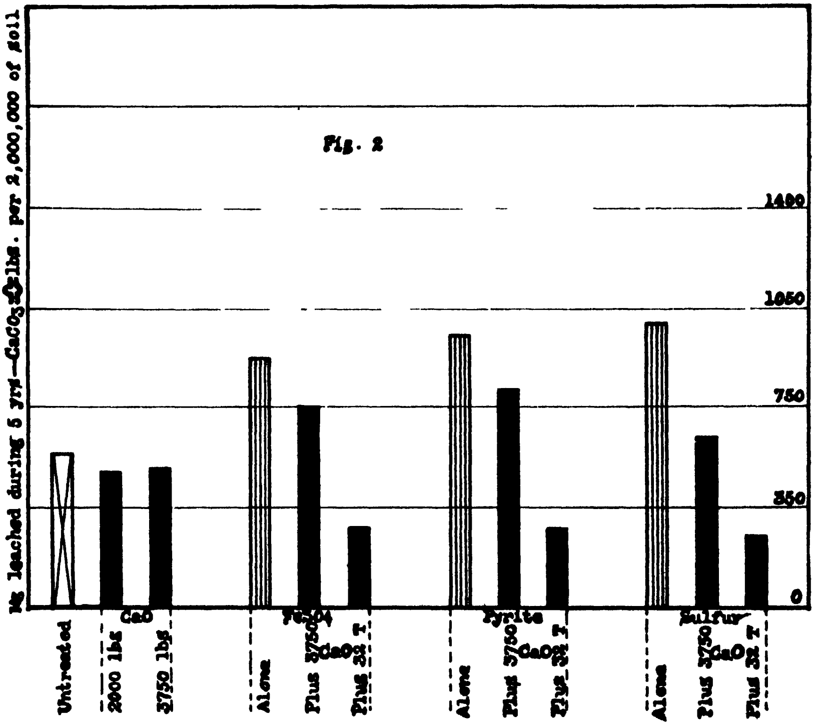

Fig. 2

Repression of magnesium by calcium.—The data of Table 2 and the comparisons of Fig. 2 are from additions of CaO corresponding to those of MgO, also with and without the supplementary additions of sulfur in three forms.

Lime alone.—In four of the five annual leachings and in the totals from both 2,000-pound and 3,750-pound additions of CaO, the amounts of magnesium are less than the corresponding amounts in the no-treatment control. The usual outgo of magnesium from this soil without treatment is about 40% as great as that of calcium, although the total CaO content is 0.217% as against 0.298% MgO, so that the extent of magnesium repression by calcium additions would not be expected to equal the repression of calcium by magnesium.

TABLE 2.—*Magnesium outgo from a loam over a 5-year period as influenced by additions of CaO, with and without sulfur supplements.*

Treatment		$CaCO_3$ equivalent per 2,000,000 lbs. of soil								
		Annual periods					5-year period			
CaO	Sulfur	1	2	3	4	5	Total	Average annual	Over control	Over group control
None	None	174	90	108	78	85	535	107	——	——
2,000 lbs.	None	159	82	61	100	75	477	95	— 58	——
3,750 lbs.	None	139	67	42	162	74	484	97	— 51	——
None	$FeSO_4$	474	140	106	147	62	929	186	+394	——
3,750 lbs.	$FeSO_4$	347	96	55	113	83	694	139	+159	—235
32 tons	$FeSO_4$	100	9	33	76	57	275	55	—260	—654
None	Pyrite	300	202	142	184	129	957	191	+422	——
3,750 lbs.	Pyrite	373	119	68	118	85	153	153	+228	—194
32 tons	Pyrite	96	48	17	87	28	276	55	—259	—781
None	Sulfur	523	151	112	132	82	1,000	200	+465	——
3,750 lbs.	Sulfur	280	99	57	112	40	588	118	+ 53	—412
32 tons	Sulfur	86	35	26	62	45	254	51	—281	—746

Lime plus sulfur.—The sulfate, pyrite, and sulfur additions without lime all gave appreciable increases in magnesium outgo (7) from the surface soil, as they did also for calcium and potassium (5), especially during the first year. But the lighter addition of burnt lime so antagonized this solvent action of the sulfate radical for magnesium that each 3,750-pound CaO addition resulted in a loss of magnesium considerably less than that from its respective unlimed sulfur-addition control. However, this ameliorative action of the smaller lime treatment was not sufficient to force back the action of the high initial concentration of $CaSO_4$—nor that of the amounts generated progressively from the pyrite and elementary sulfur—upon magnesium liberation to the extent of giving a magnesium outgo as small as that from the untreated control. But, so greatly did the heavy CaO additions offset the liberative action of $CaSO_4$—derived from combination of added lime and added or generated SO_4—that the total amount of magnesium coming out from each form of sulfur was only about one-half that from the *untreated* controls. It might be held that this effect of the heavy lime additions was due to the removal of $CaSO_4$ from the active sphere through the formation of

TABLE 3.—*Activity of magnesium in repressing calcium outgo from a loam and in increasing calcium outgo from a loam with subsoil over an eight-year period.*

Calcium content of leachings expressed as pounds of $CaCO_3$ per 2,000,000 lbs. of soil

	MgO					
No treatment	8-ton CaO equivalent		32-ton CaO equivalent		100-ton CaO equivalent	
	Total	Over control	Total	Over control	Total	Over control
			Surface soil only			
1,641	935	— 706	509	—1,132	617	—1,024
			Surface soil and subsoil			
804	2,942	+2,138	2,953	+2,149	3,653	+2,849
			Calcium liberated from subsoil			
(837 absorbed)		2,844		3,281		3,873

TABLE 4.—*Activity of magnesium in repressing calcium outgo from a loam and in increasing calcium outgo from a loam with subsoil over an eight-year period.*

Calcium content of leachings expressed as pounds of $CaCO_3$ per 2,000,000 lbs. of soil.

	$MgCO_3$					
No treatment	8-ton CaO equivalent		32-ton CaO equivalent		100-ton CaO equivalent	
	Total	Over control	Total	Over control	Total	Over control
			Surface soil only			
1,641	898	— 743	654	— 967	904	— 737
			Surface soil and subsoil			
804	2,900	+2,096	3,579	+2,775	3,366	+2,562
			Calcium liberated from subsoil			
(837 absorbed)		2,839		3,742		3,299

TABLE 5.—*Activity of magnesium in repressing calcium outgo from a loam and in increasing calcium outgo from a loam with subsoil over an eight-year period.*

Calcium content of leachings expressed as pounds of $CaCO_3$ per 2,000,000 lbs. of soil.

	Magnesite					
No treatment	8-ton CaO equivalent		32-ton CaO equivalent		100-ton CaO equivalent	
	Total	Over control	Total	Over control	Total	Over control
			Surface soil only			
1,641	1,224	— 417	1,284	— 357	1,535	— 106
			Surface soil and subsoil			
804	2,238	+1,434	2,997	+2,193	2,708	+1,904
			Calcium liberated from subsoil			
837		1,851		2,550		2,010

$3CaO.Al_2O_3.3CaSO_4.33H_2O$ (8, 9). But this explanation is not tenable, save for the results of the first year, since the effect continues long after the disappearance of $Ca(OH)_2$, which disappearance is followed by disruption of the calcium-alumino-sulfate hydrate, insoluble in $Ca(OH)_2$ solution, soluble in aqueous solution, and decomposed in bi-carbonate solutions. It is thus apparent that CaO alone gives a marked repression of native magnesium solubility—or precipitation of magnesium—and that the replacement tendency of $CaSO_4$ is obliterated by an excess of $Ca(OH)_2$ and also by its carbonate and silicate derivatives.

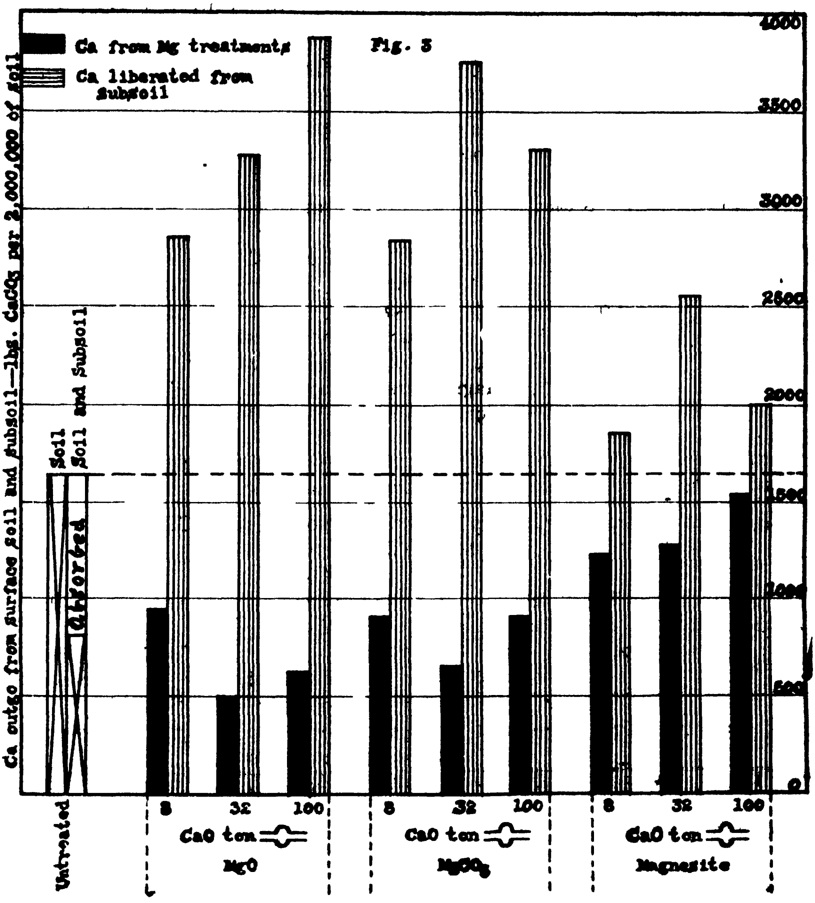
Fig. 3

EIGHT-YEAR LYSIMETER STUDIES WITH SURFACE SOIL AND SUBSOIL

Repression of calcium by magnesium in surface soil.—The eight-year study was upon a loam soil similar in type to the brown loam of the five-year experiment. It contained 0.18% total CaO and 0.30% total MgO, while its red clay subsoil contained 0.19% CaO and 0.47% MgO.

The data of Tables 3, 4, and 5 and the columns of Fig. 3 show the very definite effect of MgO, $MgCO_3$, and magnesite in diminishing the outgo of calcium from the surface soil, to the extent of almost 70% in one case. The oxide and carbonate forms were more active than the less soluble magnesite in effecting a repressed outgo for almost every annual period. In the 8-ton oxide and carbonate additions the repressive action of the last six years was due to silicate complexes, for those additions had been completely absorbed before the end of the second year (2). But in the soil-subsoil leachings from the magnesium additions, the calcium concentrations of the strongly magnesic waters were restored and greatly enhanced by calcium liberated from the subsoil. However, there was a relatively low

TABLE 6.—*Activity of calcium in repressing magnesium outgo from a loam and in increasing magnesium outgo from a loam with subsoil over an eight-year period.*

Magnesium content of leachings expressed as pounds of $CaCO_3$ equivalent per 2,000,000 lbs. of soil.

	CaO					
No treatment	8 tons		32 tons		100 tons	
	Total	Over control	Total	Over control	Total	Over control
			Surface soil only			
845	490	— 255	524	— 321	433	— 412
			Surface soil and subsoil			
1,094	2,308	+1,214	2,091	+ 997	2,528	+1,434
			Magnesium liberated from subsoil			
249		1,469		1,318		1,846

TABLE 7.—*Activity of calcium in repressing magnesium outgo from a loam and in increasing magnesium outgo from a loam with subsoil over an eight-year period.*

Magnesium content of leachings expressed as pounds of $CaCO_3$ equivalent per 2,000,000 lbs. of soil.

	$CaCO_3$					
No treatment	8-ton CaO equivalent		32-ton CaO equivalent		100-ton CaO equivalent	
	Total	Over control	Total	Over control	Total	Over control
			Surface soil only			
845	644	— 201	701	— 144	1,258	+ 413
			Surface soil and subsoil			
1,094	2,394	+1,300	2,067	+ 973	2,242	+1,148
			Magnesium liberated from subsoil			
249		1,501		1,117		735

concentration of calcium in the leachings from the controls, and the subsoil absorbed a considerable portion of the calcium derived from the surface soil.

TABLE 8.—*Activity of calcium in repressing magnesium outgo from a loam and in increasing magnesium outgo from a loam with subsoil over an eight-year period.*

Magnesium content of leachings expressed as pounds of $CaCO_3$ equivalent per 2,000,000 lbs. of soil.

	Limestone					
No treatment	8-ton CaO equivalent		32-ton CaO equivalent		100-ton CaO equivalent	
	Total	Over control	Total	Over control	Total	Over control
			Surface soil only			
845	694	− 151	886	+ 41	964	+ 119
			Surface soil and subsoil			
1,094	2,150	+1,056	1,991	+ 897	2,282	+1,188
			Magnesium liberated from subsoil			
249		1,207		856		1,069

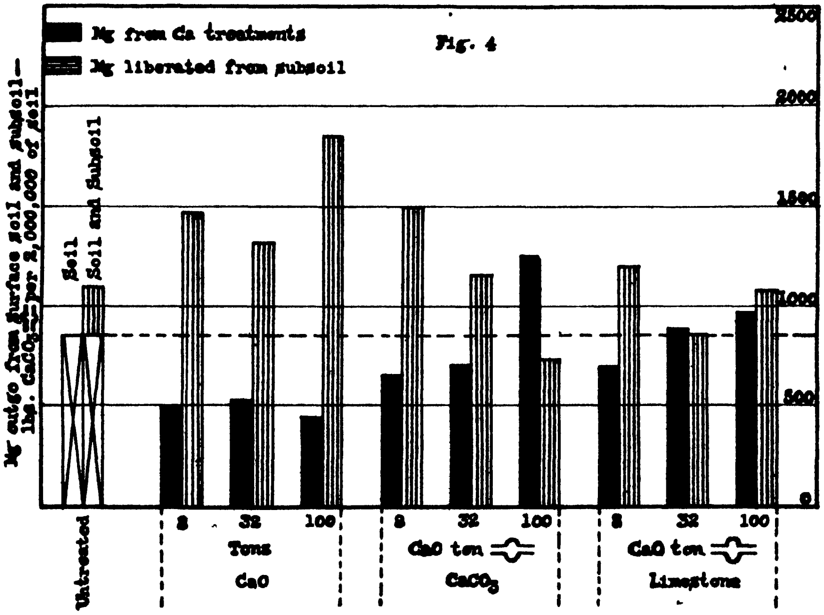

Fig. 4

Repression of magnesium by calcium in surface soil.—In Table 6 we find that all three rates of CaO caused a positive decrease in magnesium outgo, as compared with the surface soil control. The same holds for the 8-ton and the 32-ton $CaCO_3$ results in Table 7; but the reverse was found in the case of the 100-ton $CaCO_3$ addition (Table

8) due to its consistently higher results for the first three years, a period of marked biochemical activity. In a similar manner, the 8-ton limestone addition caused a repression, while the 32-ton and 100-ton additions gave some liberation. A possible explanation may be advanced for these exceptional reversals. During certain seasons of intermittent showers, insufficient to cause leachings, conditions are conducive to nitrification and sulfofication and accumulation of the biological end-products with minimum of CO_2 present. With the coming of leaching rains, such accumulations of soluble neutral salts are removed, and while the interstical spaces are filled with water there is little opportunity for CO_2 generation and attainment of a high bicarbonate concentration. During this condition of low H_2CO_3 concentration and diffusion of solutes, the greater concentration of neutral salts exerts an interchange effect. This explanation is in accord with the observations relative to the repressive effect of the excessive additions of MgO upon the interchange exerted by the $MgSO_4$, derived from the reaction between the $FeSO_4$ treatment, and the large residues of MgO or its hydroxide, carbonate, and silicate derivatives.

ZONE-TREATMENT EXPERIMENTS

In still another series of lysimeter experiments, 2,000-lb. CaO additions of $Ca(OH)_2$ were compared with calcined dolomite and four different limestone separates in surface-zone and subsurface-zone incorporations in surface soil only (11). In the former the lower zone was untreated and in the latter the upper zone was devoid of treatment. As a result of the passage of leachings from the treated zone to the lower untreated zone, and the intervention of the absorptive power of the latter, a maximum magnesium outgo variation of only 28 pounds from the control was obtained and this represented only 10.5% of the $MgCO_3$ impurities of the practically completely absorbed finer limestone separates.[4] When the leachings from the lower treated zone passed directly into the containers, the maximum variation from the controls was only 35 pounds for four years. This amount represented the repressive action of $Ca(OH)_2$ upon magnesium outgo.

DISCUSSION

From the foregoing results it is evident that unsupplemented calcium and magnesium additions show reciprocal repression upon the outgo of native magnesium and calcium present as non-carbonate, or silicate, complexes in the surface soil, when the alkali-earths are applied in economic, or excessive, amounts and mixed throughout the entire body of soil.

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[4] To appear in *Soil Science*.

The decrease of calcium outgo from the lighter MgO-plus-$FeSO_4$ combination, as compared with that from ferrous sulfate alone, may be readily accounted for by remembering that the minimum addition of magnesium was made at the rate of 2,000 pounds CaO-equivalence plus a quantity sufficient to neutralize the acidity of the acid sulfate. The ferrous sulfate of the control was therefore neutralized in most part by the native alkali-earths in the control, whereas the added MgO performed this function in the MgO–$FeSO_4$ treatment. Thus the solvent action of the $FeSO_4$ was greater than the replacement effected by $MgSO_4$ before its removal through leaching. Following the heavy and complete removal of $MgSO_4$ during the first year, the absorbed residue of the MgO addition diminished the hydrolysis of native calcium complexes or furnished bicarbonate concentrations of sufficient intensity to repress again the calcium outgo.

In the yet more marked repressions of calcium outgo from the excessive MgO–$FeSO_4$ addition, it appears that the large concentration of magnesium bicarbonate derived from the excess of MgO was responsible for an even more intensive protective action upon the native calcium. The calcium outgo from the heavy MgO-plus-$FeSO_4$ treatment amounted to only about one-third of that which passed from the no-treatment control. Hence, there was effected no substitution of magnesium for calcium—at least none that was productive of soluble forms of calcium—although the dual treatment yielded almost 3,800 pounds of magnesium sulfate to the leachings of the first year. However, even had calcium been liberated, the concentrations of magnesium bicarbonate from the excessive additions would have been sufficient to have salted out calcium carbonate. But whereas this possible factor may be advanced to explain the greater repression of the excessive additions, it would not explain the repression exerted by the lighter addition where the bicarbonate concentration of one alkali-earth was not sufficient to produce a carbonate precipitation of the other as a result of the presence of the second base in the form of soluble neutral salts.

In general, the same explanations apply to the less intensive CaO-induced repression of magnesium outgo.

The influence of the alkali-earth additions upon oxidation of the other two forms of sulfur and periodic variations in sulfate leachings involves factors of periodicity which may not be considered in the time available.

Although the unsupplemented excessive additions also gave positive reciprocal repression in the surface soil, it is equally evident that an extensive interchange of bases takes place when the surface soil leachings pass through the clay subsoil. In the heavier MgO, $MgCO_3$, and magnesite additions large amounts of calcium—in two cases over 1,000 pounds of $CaCO_3$-equivalence—are liberated in 69 of the 72 separate annual collections. The calcium liberated in the subsoil by the high-magnesic leachings from the magnesium additions to the surface soil exceed, in some cases, the amounts of calcium leached from equivalent calcium additions. If time permitted, interesting correlations could be shown between the first excessive appearance of sulfates (1)—generated by solfofication of sulfur compounds native to the soil—and magnesium bicarbonate and the appearance of replaced calcium, as these findings were influenced by intensity of magnesic incorporations. Conversely, in certain instances, the amounts of magnesium liberated by the leachings from calcium additions closely approach the amounts leached from corresponding additions of magnesium.

From these data it is evident that the action of the free soil water impregnated with calcium or magnesium salts exerted one effect upon these surface soils and another upon the clay subsoil. The soils and subsoil were all acid in character and of about equivalent CaO content and yet they function differently. The free soil water moves more slowly through the subsoil than through the surface soil, and in these experiments the subsoil depth was 4 inches greater than that of the surface soil, so that both time and volume factors may have been of effect. It is possible that a second layer of 12 inches of surface soil might act as did the 12-inch zone of subsoil.

The magnesium additions exerted a greater repressive effect upon the native calcium of the surface soil than did equivalent calcium additions upon the magnesium complexes, although the magnesium content was one and two-third times that of calcium. On the other hand, with the magnesium content 2.47 times that of the calcium, the subsoil gave a grand average of 2,306 pounds of $CaCO_3$ liberation for the nine eight-year totals from MgO, $MgCO_3$, and magnesite additions as against a similar magnesium liberation average of 1,497 pounds from the nine additions of CaO,. $CaCO_3$, and limestone. Hence, the calcium complexes, though of lesser amount, were less resistent than the magnesic combinations to both repression and interchange reactions.

The alkali-earths of the surface soil are brought into solution almost entirely by the solvent action of the biologically engendered acids—

carbonic, nitric, and sulfuric; and unless there be a large excess of magnesium complexes present to insure greater surface exposure, the more readily hydrolyzed calcium compounds will give an outgo of calcium in excess of that of magnesium. When either alkali-earth is added in small amounts there is then available a quantity of unaged absorption complexes, and in case of excesses, carbonate accumulations also, which are more readily attacked and which serve to protect the aged native complexes of both àlkali-earths. (We have shown that colloidal silicic acid functions as do the native acid silicate in the fixation of calcium (8), but more especially that of magnesium (10) additions, and in this reaction the exchange of the alkali-earth cations is with hydrogen-ions.) The calcium-, or magnesium-, impregnated solutions then passed from the surface soil area, which contains the excess of one of the alkali-earths, and into the subsoil where the mass cation effect produces a liberation of the other earth. The soluble neutral salts, the interchange-inducing solutes, more especially nitrates, pass through the subsoil much more quickly than do the bicarbonates which are stopped in large amounts and for a long period (6). The liberation in the subsoil is influenced by this absorption, which affects the proportion of bicarbonates to neutral salts.

The surface soil contains more of coarser material, and it has been subjected to direct heat absorption and possibly frequent dehydration, to repeated wetting and drying, and to cultivation. The subsoil contains more of the finer particles, it has never suffered action of the sun's rays, and it has never been dried out, nor has it been subjected to mixing. The components of the subsoil may be said to be in a more hydrated condition and to have been in this condition since genesis and therefore more reactive than those of the surface soil. In addition there is the factor of time of contact between the soil mass and the salt-impregnated leachings, which is more extensive in the subsoil than in the surface soil. Furthermore, we know that the greater portion of the subsoil is made up of zeolitic particles of sufficient fineness to possess the physico-chemical properties essential to exchange of cations. To these causes we may attribute the antithetic properties of this particular surface soil and its subsoil, and each may be assumed to be representative of a type.

While thus recognizing basic exchange as a potent factor, and one of practical importance under non-humid conditions, we must recognize the fact that the phenomena of interchange of bases may not be operative in all surface soils when alkali-earths are used under humid conditions, and that we may not rely upon one alkali-earth to liberate the other. If a soil needs calcium this element should be applied. If a soil needs magnesium, this alkali-earth should be applied. A paucity of calcium may be still further diminished by an oxide, hydroxide, or carbonate form of magnesium in economic amounts and likewise, a deficiency of magnesium, or the stability of an ample supply against hydrolysis, may be accentuated by an application of a high-calcic oxide, hydrate, or carbonate.

Assuming the soils and subsoil studied to be typical and using their leachings as criteria, we may conclude as follows:

Bicarbonate solutions of calcium or magnesium will not effect reciprocal interchange, *per se*, as measured by outgo of soluble salts, irrespective of the preponderant concentration of either earth; nor will potassium be replaced by neutral salts of either calcium or magnesium if there be present an appreciable quantity of the bicarbonate of either alkali-earth. Rather a preponderance of either earthy base, through additions, will result in a repression of the hydrolysis of the native supplies of the unadded alkali-earth. Furthermore, the liberative tendency of even an excessive concentration of a neutral salt of one base will be repressed and even obliterated by a high bicarbonate concentration of the *same base*, whether such concentration be derived from excesses of residual carbonate, or from hydrolysis of absorption complexes.

In so far as the foregoing applies to surface soil, the reverse may be said concerning a similar clay subsoil where extensive interchange of bases may be anticipated as a result of lime incorporations in the overlying surface soil.

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5. THE EFFECT OF THE NATURE OF THE EXCHANGEABLE BASES UPON THE RETENTION OF ANIONS BY SOILS[1]

C. H. SPURWAY[2]

The subject matter of this paper deals with the chemical aspects of the problem at hand. It is based on the electronic theory of valence and assumes that in the soil-salt reactions the processes taking place have for their basis the transference or sharing of electrons. Soils in contact with water solutions are the experimental conditions under consideration. The processes discussed are those which may be considered under the heading of major reactions.

The principal factors to be considered in connection with the title of this paper are as follows: Kind of soil base; quantity of soil base; ratio of base to base and of base to acid; concentration of the liquid phase; and hydrolysis and ionization.

KIND OF SOIL BASE

Studies on the fixation of cations of neutral salts by soils, and the corresponding exchange of soil bases or soil cations for them, conducted by a number of investigators, lead to the conclusion that fixation and exchange of bases in soils is a function of the kind of soil base in a condition to react with the neutral salt. The cations of the neutral salts react with unlike soil cations or bases.

Salt calcium reacts with soil magnesium, potassium, sodium.
Salt magnesium reacts with soil calcium, potassium, sodium.
Salt potassium reacts with soil calcium, magnesium, sodium.
Salt sodium reacts with soil calcium, magnesium, potassium.

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[1] Paper read as a part of the symposium on "Base Exchange Phenomena in Soils" at the meeting of the Society held in Chicago, Ill., November 17, 1925.

[2] Research Associate in Soils, Michigan State College, East Lansing, Mich.

Also, salt anions react with the soil bases and are fixed in soils whenever the conditions of the experiments are such as to cause the reaction to proceed beyond the point of solubility of the salt being formed, or whenever the concentration of the reacting ions exceeds the solubility of the corresponding salt. These conditions not prevailing, the salt anion is not fixed by soils except perhaps in very small quantities. The most active soil base in this respect is calcium because it is present in soils in comparatively large quantities, and because a relatively large number of calcium salts have a low degree of solubility. The chemical compounds studied in this connection by the author are ferric oxalate, oxalic acid, potassium citrate, potassium tartrate, tri-potassium phosphate, mono-calcium phosphate, and ammonium sulfate. The anions of all these compounds may be fixed in soils under the conditions necessary for the formation of the insoluble calcium salts of them. Also, if the soil calcium base is first replaced by potassium or sodium from a neutral salt, then the degree of fixation of the above-named anions is greatly lessened and the fixation of them may, in some cases, be entirely prevented.

It is possible that iron and aluminum may act as bases in acid soils, and although basic exchange of these elements has not been observed in the author's experiments, some results obtained seem to show that basic iron and aluminum in acid soils may be the cause of the fixation of some anions. Strong evidence exists showing that the kind of soil base has a direct bearing on the fixation of anions by soils. Other data will be shown later on in this paper.

QUANTITY OF SOIL BASE

The degree of fixation of anions also correlates with the quantity of exchangeable base, particularly calcium. If the quantity of exchangeable base in a soil is lowered by leaching the soil with strong acids, or by replacement with other bases that form soluble compounds with the anions added, as has already been discussed, the quantity fixation of the anion in question is also lowered. We have been unable to fix the sulfate ion in soils from calcium sulfate because with this solution the solubility of the salt can not be exceeded. There is not sufficient sulfate ion present in the mixture and the sulfates of the other soil bases are more soluble than calcium sulfate. But, with a higher concentration of sulfate ion, which may be obtained with ammonium sulfate, or other soluble sulfates, the sulfate ion may be fixed in soils, providing the soil contains sufficient calcium ion to exceed the solubility of calcium sulfate. Thus, a correlation between quantity of exchangeable soil base and anion fixation is exposed.

RATIO OF BASE TO BASE AND BASE TO ACID

RATIO OF BASE TO BASE

The question of exchangeable base ratios, and base to acid ratios in soils, and the correlations between these soil factors and the fixation of salt cations and anions has been given some attention by soil investigators, and is the subject which has appealed to us as being of great importance. In determining equilibrium conditions or the degree of fixation in soil-salt reactions, the possible effects of changing base–base ratios in soils may be shown by Table 1.

TABLE 1.—*Showing that the amount of fixation of cations in soils varies with the proportion of soil cations in an exchangeable condition; the total weight of soil cations remaining the same.*

Weights and equivalents of exchangeable soil cations					Equivalents of cations fixed from chlorides		
Total weight of cation	Weight of Ca	Weight of Mg	Ca equivalent	Mg equivalent	KNa or NH_4 equivalent	Ca equivalent	Mg equivalent
A 240	180	60	9	5	14	5	9
B 240	120	120	6	10	16	10	6

Assuming that the base exchange is equivalent, if the ratio of exchangeable calcium to magnesium is changed, the total weight of the two remaining the same, the fixation of cations and anions of salts by such soils would change also. In this case we have considered only two soil bases, calcium and magnesium, but a consideration of the other soil bases also capable of being exchanged still further complicates the problem and causes a large number of variations. This is a probable reason why different soil investigators, working on different soils, have obtained different ion-series of cation fixation.

RATIO OF BASE TO ACID

That various ratios of bases to acids occur in agricultural soils has been proved beyond question. This being the case, equilibrium conditions in the soil-salt reactions must change accordingly. The quantity fixation of potassium in a certain soil series of acid soils increased with an increasing ratio of calcium to silica dissolved from these soils by means of 0.2 N HCl.[3] A correlation was also found between the ratio of calcium to iron and aluminum soluble in 0.2 N HCl and the soil reaction.[4] The other soil bases and iron and aluminum seem, then, to be occupying opposite positions in the soil reactive portion; that is, iron and aluminum appear to be on the acid of the soil compound, and this may account for the failure to replace them by means of salt cations. A correlation between base-acid ratio and the pH values of soils has been noted by different investigators. The correlation between base-acid ratio and the fixation of the ions of a hydrolyzing salt appears to be the basis of the well-known Jones method for determining the lime requirements of soils. This lime requirement method shows that the ions of a hydrolyzing salt may be fixed by soils independently of each other, in this case the basic ion being fixed in the greater quantity. The reverse of this action has been observed by the author in working with K_3PO_4, both ions of this salt being strongly adsorbed or fixed by soils, in which some of the soils under experimentation with this salt were made strongly alkaline, and this effect was probably due to the presence of the hydrolyzing KOH.

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[3] SPURWAY, C. H. Studies on the reactions between soils and various chemical compounds. Mich. Agr. Exp. Sta. Tech. Bul. 51. 1921.

SOIL-SALT SERIES

The correlation of pH values and base-acid ratios; the amphoteric nature of soils as shown by the fact that soils can be titrated up and down the pH scale by means of alkalis and acids used in equivalent quantities: the position of calcium with respect to iron and aluminum as mentioned before; and, the presence of a transition point in soils with respect to soil reaction all seem to present good evidence that the soil reactive materials are of the nature of a salt series, comparable to the well-known phosphate series of salts, at least from the standpoint of their resultant effects. We have tried to locate this transition point and find it to be close to pH 5.3, but it varies somewhat from this point in different soils. All we can say about it at present is that soils above pH 5.3 have different chemical characteristics than soils having pH values below this figure.

CONCENTRATION OF LIQUID PHASE

We have considered that in order to fix anions in natural soils in quantity we must use a salt concentration of sufficient strength to exceed the solubility of the corresponding calcium salt. This applies, in general, to neutral salt treatments. In the case of hydrolyzing salts, we must consider also the nature of the salt used with respect to hydrolysis and ionization as well as its concentration (Fig. 1).

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[4] SPURWAY, C. H. Soil acidity and the hydrolytic ratio in soils. *In* Jour. Agr. Res., 11:659–672. 1917.

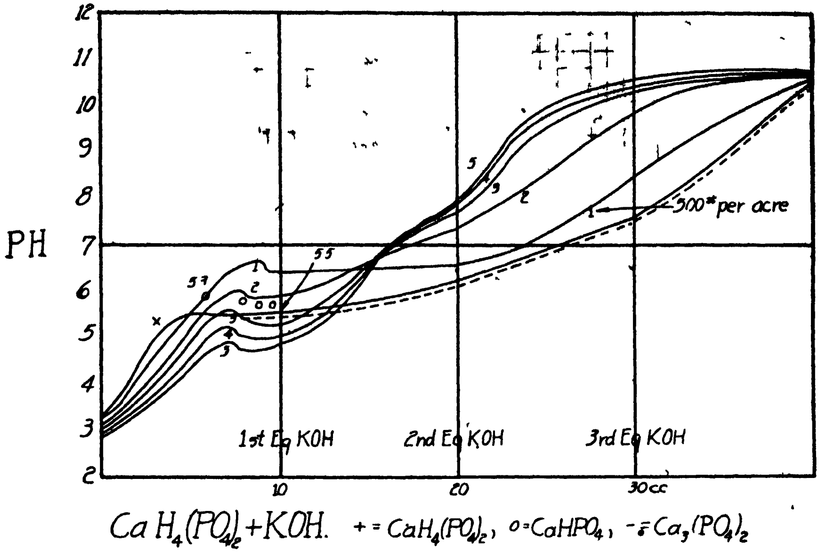

FIG. 1.

Curve 1, 0.2522 gram $(CaH_4PO_4)_2$, 0.1N KOH, 200 cc. water.
Curve 2, 0.5044 gram $(CaH_4PO_4)_2$, 0.2N KOH, 200 cc. water.
Curve 3, 1.0088 gram $(CaH_4PO_4)_2$, 0.4N KOH, 200 cc. water.
Curve 4, 1.5132 gram $(CaH_4PO_4)_2$, 0.6N KOH, 200 cc. water.
Curve 5, 2.0176 gram $(CaH_4PO_4)_2$, 0.8N KOH, 200 cc. water.
Smooth curve 0.2522 gram $(CaH_3PO_3)_2$, 0.1N KOH, 200 cc. water, time 14 days.
(From Master's thesis of Russell H. Austin, Michigan State College, 1925.)

The sharp inflections in curves 1 to 5 of direct titrations represent the points where precipitates were first observed during the progress of the titrations. The data of this experiment show a possible correlation between fixation of phosphorus from monocalcium phosphate, soil reaction, and concentration of the liquid phase and that phosphorus may be fixed in soils without having any more calcium present than that in the phosphorus salt.

HYDROLYSIS

That hydrolysis of soil bases plays an important part in the soil reaction, and in the fixation of anions by soils, may be shown by the charts in Figs. 2 and 3.

The soil samples (Fig. 2) were first treated with the neutral salts in strong concentration, as indicated on the chart, then washed with

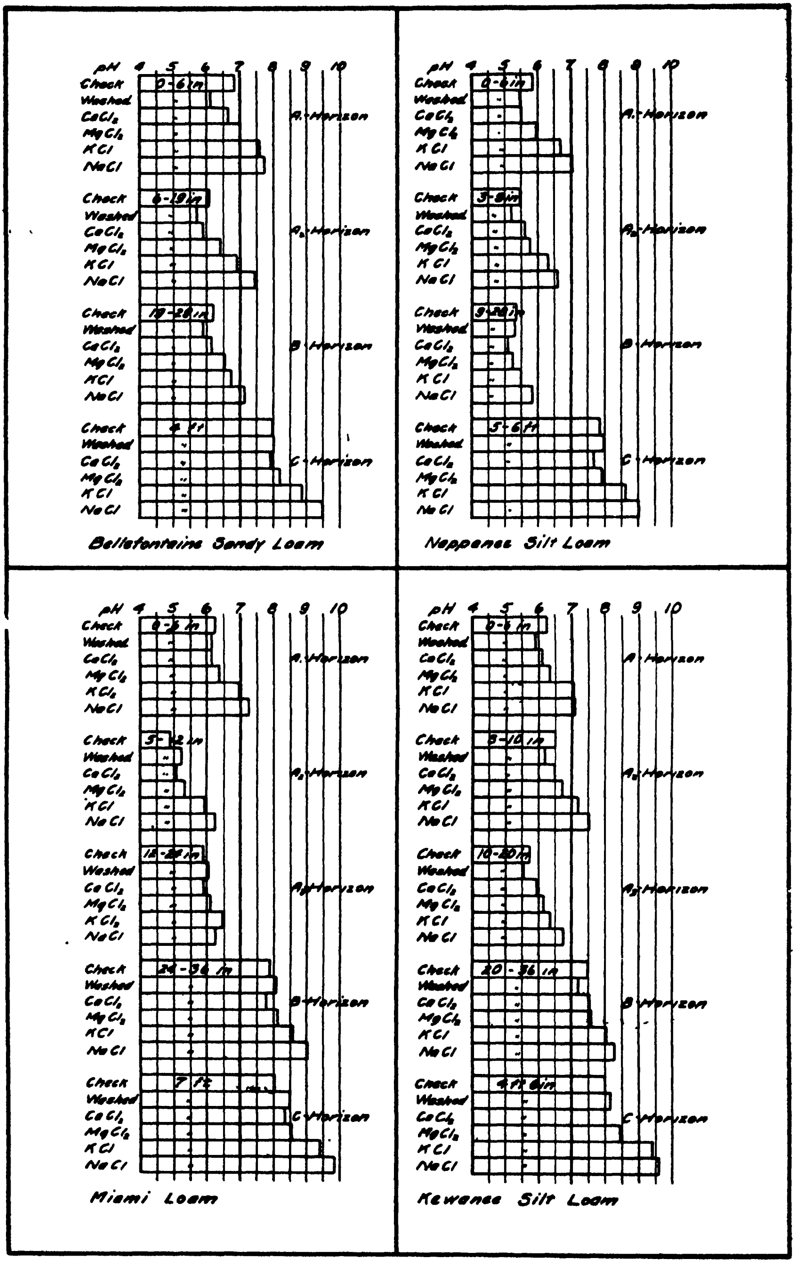

FIG. 2.—Variation in pH values of horizons and corresponding residual effects of neutral salt treatments on four soil types, showing relative power of fixed cations to form hydrates. (From Soil Sci., 21:71. 1926.)

water until chlorides were practically absent from the washings. Twenty grams of soil and 50 cc. of neutral distilled water were the portions taken, and the samples were shaken for a period of seven hours. It is believed that the changes in soil reaction induced by the different treatments are due to the hydrolysis of the strong bases fixed in the soils.

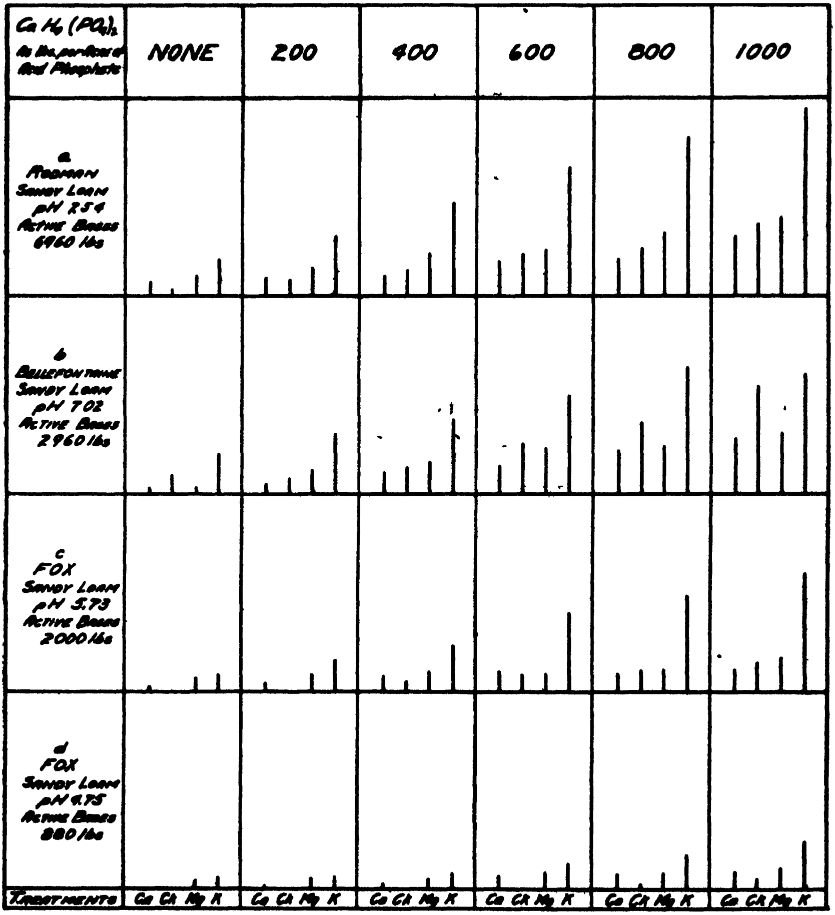

FIG. 3.—Comparative solubilities of P_2O_5 for various quantities of phosphate added to the different checks and salt-treated soil samples. (From Soil Sci., 19:399. 1925.)

The soil samples used for this experiment (Fig. 3) were first treated in about the same manner as those used in the experiment illustrated by Fig. 2, washed, dried, and then retreated with mono-calcium phosphate in quantities as indicated on the chart, using 40 grams of soil and 100 cc. of water, and the soluble phosphorus determined in the soil extracts after seven hours contact between soils and the phosphate solutions. A relationship between solubility of phosphorus and kind and quantity of base and concentration of the liquid phase is shown. The degree of fixation is the reverse of the degree of solubility of phosphorus.

SOLUBILITIES AND IONIZATION

The concentrations of hydrogen ion and of hydroxyl ion in soils have been determined by accurate methods and have been studied extensively. Little is known, however, about the concentrations of the other soil ions which may be in the soil solutions. And, so far as the author is aware, practically nothing is known about the solubilities of the reactive soil components, either alone or in the presence of added salts. However, if these soil-salt reactions are chemical reactions, as much experimental evidence seems to show to be the case, then their equilibrium conditions are determined by certain ionic relationships, and until we know what these ionic relationships are, we can not hope to apply chemical laws, particularly the mass action law, to them. In the author's opinion, here lies a fruitful field for soil investigators.

INSTABILITY OF REACTIVE SOIL COMPOUNDS

From the chemical standpoint the reactive soil materials appear to be made up of comparatively strong bases united with weak, complex acids of low solubility. This being the case, we should expect these compounds to be quite unstable, or to become unstable under conditions of low base-acid ratio or lack of bases. The addition of bases, acids, or salts to soils, then, may greatly alter the nature of the reacting soil components; or they may be broken up and their chemical characteristics changed during the course of a reaction. For example, iron or aluminum may be basically exchanged as chlorides but neutralized in the soil and the iron or aluminum precipitated as hydroxides; or soil iron or aluminum may be precipitated in soils as hydroxides when soils are undergoing treatment with strong bases.

CONCLUSIONS

We must conclude, therefore, that of the many soil factors influencing the fixation of anions by soils the kind of base, the quantity of base, the ratio of base to base and of base to acid, and the degree of hydrolysis and ionization of both soil bases and soil acids are of great importance. Also, from a consideration of these factors, we can understand that when we change soils or change salts during the course of an investigation, we also change our basis of comparison, and our results can not be compared directly one with the other. It is only when we bring the different soil samples under investigation to some definite known condition with respect to the factors mentioned, by some preliminary treatment, that we can hope to obtain comparable results on them. At the Michigan Station we have paid some attention to these points, and in our experimental work, whenever we have been able to control these factors, we have obtained some very interesting and instructive results.

GENERAL DISCUSSION

F. W. PARKER

Dr. Kelley has pointed out that the absorption of a base from an alkali, such as $Ba(OH)_2$, is different from base exchange with neutral salts; and that the alkali reacts with soil constituents which do not react with a neutral salt by base exchange. That this is the case and that the alkali reacts with non-colloidal soil constituents as well as colloidal constituents has been shown by results obtained at the Alabama Station.

The separates of several soils have been studied as to their colloid content, their content of replaceable base, and their absorptive capacity for an alkali, $Ba(OH)_2$. The replaceable base content of the different separates was found to be directly proportional to the colloid content of the separates, indicating that non-colloidal soil constituents do not contain replaceable base. However, when the absorption of $Ba(OH)_2$ was studied there was no correlation between the colloid content of the separates and the amount of base absorbed. Evidently a considerable amount of base was absorbed or neutralized by the non-colloidal constituents of the soil. In several instances the separate next to the colloid in size of particles, usually containing 50 to 90 % colloid, absorbed as much or more base than the soil colloid itself. It is apparent, therefore, that the non-colloidal constituents of a soil will react with an alkali but do not possess the property of base exchange with neutral salts. The soil colloid reacts with both the alkali and the neutral salt but in most cases the amount of base absorbed from the alkali is considerably in excess of the amount of replaceable base in the colloid.

J. S. Joffe

I should like to add to Dr. Kelley's remarks about the influence of the H ions in unsaturated soils that, in our experiences at New Jersey, the acid soils of the soil fertility plats with a pH of 4.6–4.8 do not show any coagulation effect. On the contrary, a water extract of these soils is very turbid, does not settle for a long time, and contains a large quantity of organic matter in suspension. This would indicate that the H ions exert at times a coagulating, at times a peptizing effect.

In this connection it is interesting to note the work of Sokolovski (Ann. Petrovski Acad. Sci., Moscow, Russia, 1919). He differentiates the active and passive fractions of organic matter in the soil. The former is the one which is capable of base exchange and, when in an unsaturated condition (all basic cations replaced with H ions), is water soluble. It is very probable that the large amount of this active portion of organic matter is being lost from the acid soils in the soil fertility plats at New Jersey.

There is, however, another point to consider here. When the H ions begin to peptize the state of aggregation changes, e. g., the degree of dispersion increases, the amount of sol increases, and the soil becomes impervious just the same as at the other extreme of peptization under alkaline conditions as we have in alkali soils.

The results obtained by Parker on the colloid content of soil by the ratio method on the basis of base exchange capacity of soils are significant inasmuch as they are in agreement with the work of the Russian workers Gedroiz, Sokolovsky, and Glinka. The work at New Jersey described in a paper by Joffe and McLean, to appear in Soil Science, vol. 21, also shows that the vital processes of the soil are to be found in the colloidal fraction.

The disagreement found in some of the soils in respect to their colloid content on the basis of the ratio $\frac{\text{base exchange per gram of colloid}}{\text{base exchange per gram of soil}} \times 100$ may perhaps be explained by the following. Parker followed the method of Kelley and Brown, whose work is based on the investigations of Gedroiz. In my opinion, the procedure followed by Kelley and Brown does not get out all of the replaceable cations. In our work at New Jersey we found that it takes 4 to 5 liters, if not more, to get out most of the replaceable cations.

W. P. KELLEY

In connection with the question of base exchange that may result from the practical application of commercial fertilizers or of lime and magnesia and their carbonates, it seems desirable to emphasize two points to which I briefly alluded in the introduction to this symposium, namely, the influence of concentration and the effect of H ions. As regards the former it may be said that, while the exchange of bases may not be very great when solutions of high dilution are used, it is not necessarily negligible where small amounts of soluble salts are applied as fertilizer. Although the application of fertilizers containing potassium or ammonium salts may be small in proportion to the soil mass, both general reasoning and soil solution studies agree in showing that the resulting concentration of K or NH_4 in that portion of the soil moisture which is in immediate contact with the particles of the added salt may be materially increased. In fact, it is probable that the adjacent moisture films may approach saturation at least temporarily. Since base exchange is an instantaneous process, a displacement of Ca may consequently take place around these particles.

As is well known, the application of alkaline substances such as lime or magnesia usually results in a decrease in the H-ion concentration of acid soils. We may safely say that the chief effect of such application, so far as ion exchange is concerned, will involve an exchange between the base of the substance applied and the H ions of the exchange complex, which will result in a consequent lowering of the H-ion concentration of the soil solution. In this case the concentration of dissolved Ca or Mg will be determined largely by the solubility of the substance applied or of the compounds formed, and the solubility of these compounds may in some cases be too low to produce any considerable exchange with the alkali earth bases originally present in the soil. However, the lowering of the H-ion concentration probably reduces the solvent power of the soil solution. Hence the application of lime might result in a decrease in the amount of magnesium that passes out in the drainage water, and similarly the application of magnesia might reduce the calcium content of the drainage water.

I should also like to point out that there is need for much additional study on ion exchange in soils, particularly as effected by ordinary fertilizer applications and the liming of acid soils. Moreover, the analytical methods now in use are not entirely satisfactory, especially when the soil contains $CaCO_3$. In the proportion to which this symposium serves as a stimulus to investigation will its chief purpose be attained.

G. J. BOUYOUCOS

The results presented by Parker and Pate on the influence and nature of replaceable base upon the heat of wetting of soils and soil colloids are very important and significant. They show clearly, first of all, that there are other factors besides those presented by me in a former publication[1] which influence the heat of wetting. It is admittedly difficult to explain definitely just how the saturation of soils and soil colloids by various bases affects the heat of wetting, especially when it is considered that the soil colloids appear to be quite stable and resist change very strongly. For instance, some soil colloids can be heated to 230° C., or treated with very concentrated acid, and yet their heat of wetting is not changed at all.

There seem to be two possible hypotheses which may be offered for explaining the results obtained by Parker and Pate. The first is that the bases combine with the colloidal complex and form a new substance which naturally would have different characteristics and consequently different heat of wetting. The second is that the bases merely affect the nature of the surface of the soil colloid either making it more active or less active and thereby changing the heat of wetting. In the paper already cited I said, "Our present knowledge concerning the physical condition or nature of surfaces which makes material active or inactive is very meager. It appears, however, that when hydrated materials are dehydrated, porous surfaces are made smooth or vitrified and the activity or affinity of the material for water is greatly reduced or disappears entirely. On the other hand, soils which are allowed to undergo decomposition and hydrolysis having formed soil particles and colloids which are in a state of hydration and have a rough, porous and felt-like surface, have enhanced activity and affinity for water, which are probably proportional to the degree to which these conditions have progressed." It is very possible that in the second hypothesis may be the explanation for the results under consideration. The bases adsorbed could form a sort of a film on the surface of the soil colloid or make them more active or less active, and thereby affect the heat of wetting accordingly. On the other hand, the first hypothesis cannot be very well ignored.

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[1] BOUYOUCOS, GEORGE. The chief factors which influence the heat of wetting of soil colloids. *In* Soil Sci., 19:477-482. 1925.

F. O. Anderegg

The hypothesis advanced by Dr. Kelley that the hydrogen belonging to an oxygen attached to the basic aluminum rather than one connected with the acidic silicate group does not seem very plausible either chemically or in view of recent work on the relation between the M_2O_3:SiO_2 ratio, colloid content and base exchange. The difference in character of the irreversible silica gel and the reversible soil colloid gels will hardly allow the conclusions drawn from the study of one system to be safely applied to the other.

The use of large quantities of soil and leach water, as in Dr. MacIntire's studies, tends to iron out many minor discrepancies that are apt to occur in working with small amounts of material. A more complete analysis of the soil used, mechanical, chemical, and colloidal, and of the leachings would add greatly to the value of the work. For instance, if the total amounts and concentrations of all the bases, including pH, in the leach water were known, one could apply an equation based on well-known principles of equilibrium to decide between different possible reaction mechanisms. The Donnan membrane equilibrium[1] seems to give a satisfactory preliminary fundamental method of treating base exchange in soils. In so complicated a system it is not surprising that every experimenter is talking about a different thing. In order to provide a common fundamental basis, the following is respectfully proposed as a working hypothesis.

The thin envelope of solution just outside the soil particle containing the ions of the "electric double layer" is called solution I, while the great bulk of the solution is II. Let us consider the case of colloidal clay which has been freed from all replacable bases and which is being treated with neutral chloride solutions. The membrane equilibrium principle shows us that

$$\frac{[Na^+]\,I}{[Na^+]\,II} = \frac{[H^+]\,I}{[H^+]\,II} = \frac{[Cl^-]\,II}{[Cl^-]\,II} \quad \text{or} \quad \frac{[Na^+]\,I}{[H^+]\,I} = \frac{[Na^+]\,II}{[H^+]\,II} \qquad (1)$$

At the surface of the particles we have ionization of some of the first hydrogen capable of being replaced so that where C^- is the aluminosilicic group after the hydrogen has left HC, $HC \rightleftarrows C^- + H^+$

Similarly for the sodium compounds, $NaC \rightleftarrows C^-Na$.

On setting up the mass action expressions for these two equilibria, solving each for $[C^-]$ and equating we get:

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[1] A good exposition is given by J. A. Wilson in Chapter 1 of "Colloidal Behavior," edited by Bogue, and published by McGraw-Hill, 1924.

$$[C^-] = \frac{[HC]}{[H^+]\ I}\ kh = \frac{[NaC]\ k\,Na}{[Na^+]\ I}$$

where the k's are the respective ionization constants. Rearranging and comparing with (1) we have;

$$\frac{[Na^+]\ II}{[H^+]\ II} = \frac{[NaC]\ k\,Na}{[HC]\ k\,H} \text{ or } \frac{[Na^+]\ II}{[H^+]\ II} = \frac{[HC]}{[NaC]} = \frac{KNa}{kH} = K1 \qquad (2)$$

If a bivalent ion like Ca were used in place of Na^+ the equation would be

$$\frac{[Ca^{++}]\ II}{[H^+]^2\ II}\ \frac{[HC]^2}{[CaC_2]} = \frac{K}{K}\,\frac{Ca}{{}^2h} = K \qquad (3)$$

These equations give the relation between the base in solution and that in combination with the soil.

Actually more than one hydrogen is replaced, especially with the addition of more salt, so that similar expressions are required for K_2, K_3, etc. As the charge on clay particles increases the difficulty of removal of more hydrogens increases and the corresponding equilibrium constants will increase exponentially in some such way as $K_2 = K_1^{(1+2)}$, $K_3 = K_2^{(1+2+3)}$. The difficulty of replacing all the hydrogens by metallic ions from neutral solutions depends upon the great change in the equilibrium constants. On adding a hydroxide the free energy increase of water formation causes the replacement of more hydrogens

At present we can only make a very rough estimate of the hydrogens replaced by neutral salt solutions. We might use provisionally an exponent to give a sort of statistical mean for the k's,

$$\frac{[Na^+]\ II\ [HC]^n}{[H^+]\ II\ \ [NaC]} = K$$

This formula has been applied more or less empirically, but quite successfully, to base exchange in a permutit zeolite by Rothmund and Kornfeld.[1] In making experiments to test out the applicability of this formula to soils a very carefully standardized material must be used.

S. A. MATTSON

I have been asked how to account for the wide differences in the electrokinetic behavior of different soil colloids. We have seen that soil colloids with a high silica content are strongly electronegative, as measured by the quantities of methylene blue required to neutralize their charge, while colloids high in sesquioxides show a less buffered negative charge. This is true whether the colloids are saturated with exchangeable bases or unsaturated, as when these bases have been removed by electrodialysis.

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[1] *In* Zeit. anorg. allgem. Chem., 103:129. 1918; 108:215. 1919

These differences might therefore be accounted for by a study of the electrokinetic behavior of the component or constituent parts themselves. Silica is always electronegative in ordinary aqueous solutions and has no isoelectric point in acid solutions. It is therefore what Michaelis calls an acidoid, the sesquioxides, on the other hand, may be either electronegative or electropositive, depending on the pH of the solution and are, in the terminology of Michaelis, ampholytoids. Their isoelectric point lies very near the point of neutrality.

An important question often raised is, Do soil colloids have an isoelectric point governed by the pH of the solution? As far as the soil colloids here studied are concerned this question can be answered.

The curves in Fig. 1 show the speed and direction of electrical migration of the six soil colloids in solutions of HCl of increasing concentrations.

It will be seen that the charge of the Fallon, Sharkey, and Marshall soil colloids which are all comparatively high in silica is not much affected by an increase in the H-ion concentration. The Sassafras and the Norfolk soil colloids, which have a high sesquioxide content, become, on the other hand, isoelectric at a H-ion concentration somewhat above a normality of 0.001. The Aragon soil colloid, which is a near laterite, approaches in electrokinetic behavior the pure sesquioxides. This colloid assumed a strong positive charge even in a saturated solution of CO_2.

In this connection it is significant that the Aragon soil colloid, which in the neutral $CaCl_2$ solution adsorbed appreciable quantities of Ca, lost this power entirely in the $CaCl_2$ solution when it was saturated with CO_2 in which this colloid is electropositive.

Although not shown in Table 2 of my paper, it might be added that the Sassafras and the Norfolk soil colloids adsorbed only mere traces of Ca from a $CaCl_2$ solution which was made normal 0.01 with respect to HCl, while the other colloids high in silica adsorbed appreciable quantities of Ca.

The hydroxides of both iron and aluminum adsorb considerable quantities of bases from alkaline solutions in which these colloids are electronegative. The adsorbed base, the quantity of which varies with the OH-ion concentration, may be displaced with NH_4Cl. In acid solutions in which the hydroxides are electropositive they were found to have entirely lost the power to adsorb cations. This relationship between the sign of charge and adsorption of ions is, of course, not surprising, since the charge of the particles depends on ionic equilibria.

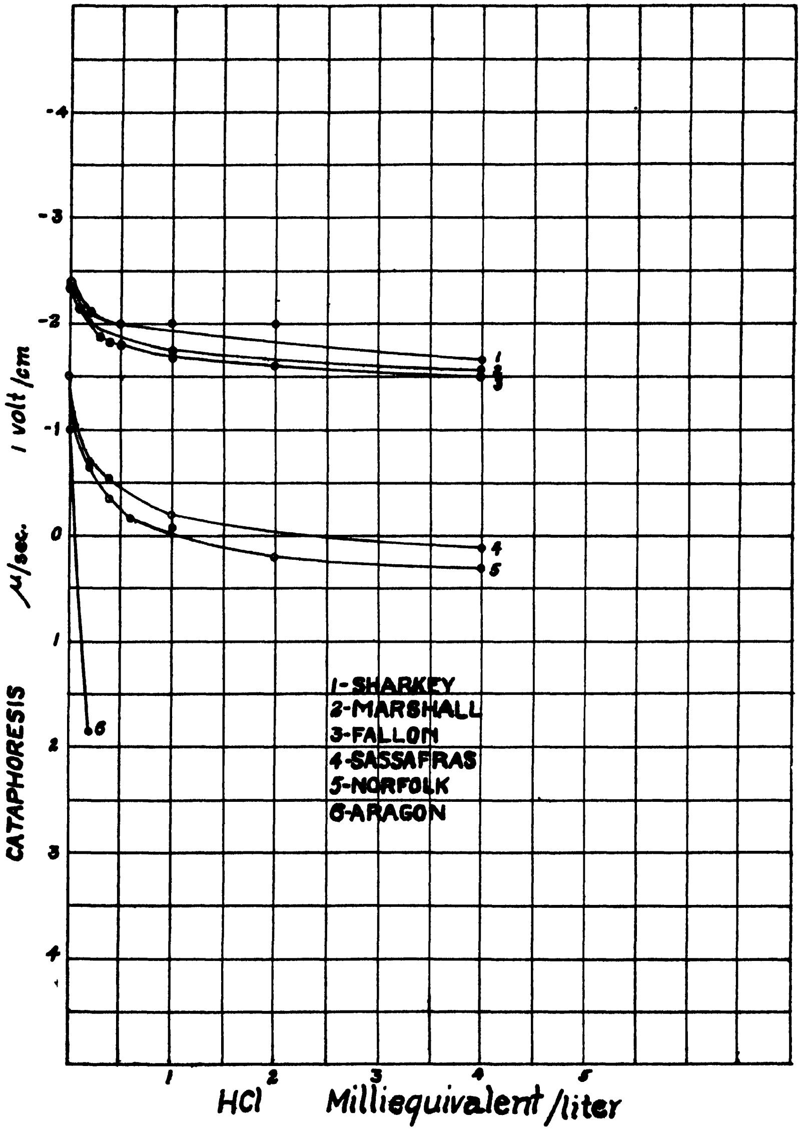

FIG. 1

RICHARD BRADFIELD

These papers and the discussions of them have raised enough questions to keep us all busy for several years if we are to answer them with the accuracy that their importance demands.

Dr. Kelley has discussed the liberation of bases by soils when treated with normal NH_4Cl. Dr. MacIntire has discussed the repressive influence of $CaCO_3$ upon the loss of Mg from the soil. At first sight these results seem conflicting, but I think that a more careful analysis will indicate that they are both to be anticipated, and studies made at Missouri show that both types of influence, equivalent exchange and no exchange can be obtained in the same soil, with the same cation, at the same concentration, by the proper control of the H-ion concentration at which the equilibrium is established.

The term "saturated with bases" has been very frequently used in these discussions and apparently with different meanings in different cases. In any new science new terms must be carefully defined until their meaning is clearly understood by all. If we mean by the term "saturated with bases" the complete replacement of H^+ by the cation used, I am rather doubtful if complete saturation is ordinarily obtained by leaching with normal NH_4Cl until 1 liter of leachings is obtained. The extensive investigations of Gedroiz, Hissink, Kelley, and others furnish strong evidence that practically all the replaceable Ca and Mg is obtained by such a process, but the evidence as to the removal of replaceable H^+ is not so conclusive. Gedroiz prefers to use normal $BaCl_2$ to remove H^+, because of the fact that the Ba ion is more strongly adsorbed by soil colloids than the NH_4 ion. But I still wonder if he obtains complete removal of the replaceable H^+ ions, even with $BaCl_2$, unless he uses a very large amount of leaching solution. Is it not possible that equilibrium may be established between neutral normal $BaCl_2$ and the soil complex before all its H^+ has been replaced?

If our base exchange studies are to be put upon a satisfactory quantitative basis, we must have a satisfactory reference condition to which all soils can be readily brought. I do not feel that the neutral point, that is pH 7, is a satisfactory reference point. It would be decidedly empirical and difficult to reproduce. Leaching a soil with a neutral salt does not necessarily render it neutral. In the case of the neutral salts of the alkalis, as soon as the excess of salt is removed the soil becomes alkaline in reaction. If every soil possesses a definite, reproducible, easily detectible capacity for absorbing bases, the most desirable reference point would be either the point of complete saturation with one base or that of complete depletion of all bases (saturation with hydrogen ions).

I pointed out in 1922 that if standard solutions of alkali were titrated conductometrically with acid colloidal clays that definite, reproducible endpoints which were independent of the nature of the base might be readily obtained. Hissink has suggested conductometric titration with $Ba(OH)_2$ as a means of determining the saturation deficit or replaceable H^+ in soils. The work of Kelley, Parker, and others indicates that the action of $Ba(OH)_2$ on a soil is very different from that of $BaCl_2$. Soils absorb such enormous quantities of the alkali that many have been led to believe that forces other than those responsible for the simple exchange reactions of the aluminosilicic and humic complexes are involved. On the other hand, there seems to be little doubt that the absorption of part of the alkali in the case of acid soils is due to a simple neutralization of the replaceable H^+. If these two different processes proceed simultaneously, it may, of course, be impossible to evaluate the rôle played by each, but if they are successive reactions it should be possible to detect where one ends and the other begins. Parallel conductometric and hydrogen electrode titrations of colloidal clay show that the first and sharpest inflection point in the former occurs at a pH of about 8.5 in the case of the latter. This value is about that of many normal calcareous soils, and I am inclined to believe at present that it represents the endpoint in the neutralization of the acid aluminosilicate complex, or the saturation point as defined above. If we continue to add alkali, the aluminosilicate complex breaks down in a manner analogous to that obtained in a Na_2CO_3 fusion, with the formation in the case of $Ba(OH)_2$ of barium aluminate and barium silicate, both of which are insoluble. This second reaction may account for the almost indefinite absorption of $Ba(OH)_2$ from strongly alkaline solutions, noted by Kelley, Parker, Joseph, Cowan, and others.

There is great need for more exact information regarding the nature of the exchangeable bases and the degree of saturation of a soil with bases and the physical condition of soils. Hissink obtains flocculation with Ca at concentrations approximately equivalent to 90% the saturation capacity. In the case of the acid Putnam clay at Missouri, the minimum concentration of $Ca(OH)_2$ causing complete flocculation is about 130% of the saturation capacity.

Joffe pointed out above that New Jersey soils with pH values as low as 4.6 were perfectly stable, and he considers this an indication that H ions at times exert a peptizing action. I have come to feel that the classification of ions into peptizing and coagulating types is not fundamentally sound and is generally misleading. Is there any theoretical reason why any ion cannot be either peptizing or coagulating under appropriate conditions? The Na ion is commonly considered a peptizing ion, but we know that saline soils are always in better physical condition than the same soils after the excess of sodium salt has been leached out and a true alkali soil produced. On the other hand, a coagulating influence has been commonly ascribed to the Ca ion. But this again depends on conditions. I know of no data that indicate that the ordinary light application of lime of 1 to 5 tons, used to sweeten sour soils, produces any appreciable improvement in the soil's physical condition. In the case of the Putnam subsoil over 15 tons $CaCO_3$ per acre are required to produce complete flocculation. It is possible to prepare clays as acid as pH 3.0 by electrodialysis which are perfectly stable.

Several papers have recently appeared in which the term "critical pH value" has been used. This term, too, is misleading. By suitable treatment a clay can be rendered stable at pH values ranging from 3–10, depending upon the degree of saturation, nature of the exchangeable bases, amount of humus, etc.

This question of the stability of soil colloids seems to be rather definitely linked up with (1) the degree of hydration and (2) the electric charge on the individual particles. The careful work being done by Mattson on cataphoresis should throw much light on the question.

BOOK REVIEWS

WHEAT BREEDING INVESTIGATIONS AT THE PLANT BREEDING INSTITUTE, CAMBRIDGE

By Sir R. H. Biffen, F. R. S., and F. L. Engledow, M. A. Ministry of Agriculture and Fisheries. Research Monograph, No. 4. London (1926), pp. 114, 30 figures, Price 2 shillings, 6 pence.

A publication of much more than usual interest and value has only recently come from the Cambridge Plant Breeding Institute of which Professor Biffen, the pioneer English wheat breeder of the post-Mendelian period, is Director. This research monograph forms one of a series, the purpose of which is to give, in the language of everyday life, an account of the research in progress and to explain the bearing of research upon practical agriculture. The use of technical terms has been reduced to a minimum so as to enable farmers to become acquainted with the important results of modern investigation. The present volume, however, will keenly interest a much wider group than the farmers of England. Every cerealist, agronomist, plant breeder, cereal pathologist, and flour mill chemist, in whatever wheat growing country of the world, who carefully reads this progress report will certainly be well repaid and greatly encouraged in his own efforts.

The following are some of the topics which are treated in more or less detail: English wheat growing conditions and the wheat grower's problem; Mendelian heredity; linkage; differences in chromosome numbers; sterility, and other complications; description of forms used for crossing; methods of breeding, crossing operations, and the propagation of hybrids; the wheat yield problem; lodging and straw characters; spring wheats for England; breeding disease-resistant wheat; breeding for quality and the tests for "strength" in wheat; and the introduction of Yeoman, a "strong" wheat for England.

Since this publication can be easily obtained by readers of this JOURNAL, a lengthy review seems unnecessary. A few quotations and comments, however, may be of immediate interest.

In the opinion of Professor Biffen, wheat will probably be grown in the near future on an increasing scale (in England) and with some profit to its producers. Taking everything into consideration, England is probably the best country in the world from the wheat producers point of view, for serious droughts are unknown, rusts cause much less damage than in many other wheat-growing countries, losses from winter killing are not large, and yields (averaging 32 bushels per acre) show an unusually low fluctuation from year to year. The greatest need in the improvement of English wheats, then, is in their quality, for in this respect they compare very unfavourably with the hard wheats imported from the United States and Canada.

The authors' discussion of the yield problem is particularly thorough and enlightening. History records that in Manorial times about 10 bushels per acre was the general yield of wheat in England. Slow increase is traceable to 11.2 bushels in 1699, some 23 bushels in

1770, and in 1883 about 30 to 32 bushels. Since 1883 the average yield of wheat in England has shown no noteworthy increase. Thus we can be sure that the wheat-yield problem in England now is of the first order of difficulty. Present methods seem likely to produce new varieties which outyield the old ones by 3 to 5% only. To measure such small but economically important increases, very accurate methods of yield testing are necessary.

These English cerealists vigorously champion the view that single plat tests cannot give yield figures of proved reliability, and that to conduct them and to publish their misleading figures is a waste of time and money. The "chess-board" test, which in some respects resembles the centgener method formerly in common use at many American stations, is described and recommended as one which combines accuracy with convenience.

Definite progress is reported in the efforts to breed stiff-strawed wheats capable of carrying the heavy crops produced under conditions of intensive cultivation. The photograph of a plat of Rivet wheat in a gale of wind is unusually clear and sharply defined.

Most cereal breeders and cereal pathologists are already familiar with Professor Biffen's early studies of the inheritance of resistance to yellow rust and of the production of the resistant variety, Little Joss. As regards the breeding of forms resistant to black rust, a somewhat novel view is held by the authors, who consider it probable that this greatest of all wheat problems will ultimately be solved by means of crosses between *T. turgidum* and *T. durum*.

The paragraphs on ergot will interest American workers, who are not unaccustomed to observing this disease on wheat. This fungus is far from common on *Vulgare* wheats in England, but F_2 and subsequent generations of Rivet x *T. vulgare* crosses contain many ergotted plants. One F_2 generation of Rivet x Red Fife contained 10% of ergotted plants, and an acre plat of a particularly attractive and wholly fertile selection of this same cross contained such an enormous crop of ergots that it had to be destroyed.

Perhaps the most interesting chapters of this monograph are those dealing with quality in wheat and telling of the remarkable improvement in English wheats which Professor Biffen and his associates have effected in the production and distribution of the new variety Yeoman, a cross between (Canadian) Red Fife and (English) Browick. This variety compares favourable in yield with others in general cultivation, and in quality it is incomparably superior to ordinary English wheats. Yeoman wheat was first distributed to farmers in 1916, and in 1925 was grown on more than 100,000 acres in the East of England.

Professor Biffen and his staff are not content to rest easy in the knowledge that Yeoman is the best quality wheat in England, but are continuing their active efforts to produce still better high-yielding, "strong" wheats, adapted to the different wheat-growing areas of England.

The Ministry of Agriculture, who largely support these investigations, Cambridge University, and the authors are all to be heartily congratulated on the production of this very readable and informative monograph. Still more credit is due to them for the new varieties and for the additions to genetic knowledge therein reported. (J. H. P.)

ROOT DEVELOPMENT OF FIELD CROPS

By J. E. Weaver, Professor of Plant Ecology, University of Nebraska. McGraw-Hill Publications in the Agricultural and Biological Sciences, C. V. Piper, Consulting Editor. McGraw-Hill Book Co., Inc. New York. 291 pp. 116 figs. 1926.

"The materials for this book * * * * have been taken largely from the following publications by the Carnegie Institution of Washington: 'Ecological Relations of Roots,' Publication 286; 'Root Development in the Grassland Formation,' Publication 292; 'Development and Activities of Roots of Crop Plants,' Publication 316; and 'Root Behavior and Crop Yield under Irrigation,' Publication 357. The first two are by the writer, and the third and fourth by the writer and co-authors, Dr. Frank C. Jean and Dr. John W. Crist." (From author's Preface.)

This book has its origin in the extensive original work done by the author and his co-workers at Nebraska. Differing from the previous formal scientific reports by omitting most of the original detailed data, by including extensive reviews and conclusions from the work of other investigators, and by presenting the material in a somewhat less technical form, the present book will make the author's special work in this field available to students and other interested readers in a suitable form for general reference or text-book use. Probably no other author could discuss this particular subject with equal familiarity with the original work in the field.

The general scope of the subject matter which is included in the book is indicated by the chapter headings, as follows: The Environment of Roots—The Soil; How Roots are Built to Perform their Work; Root Habits in Relation to Crop Production; Root Habits of Native Plants and How they Indicate Crop Behavior; twelve chapters dealing with Root Habits, respectively, of Wheat, Rye, Oats, Barley, Corn, Sorghum, Various Meadow and Pasture Grasses, Sugar Beets, Alfalfa, Various Clovers, the Potato, and Sunflowers; and Methods of Studying Root Development.

In each chapter, the subject is presented clearly, concisely, and with a keen discrimination as to the essential or desirable material. Frequent reference is made to the supporting literature, included in the excellent bibliography of 232 titles. Taken altogether, the book is undoubtedly the best treatise on its particular topic that is likely to appear for a long time to come. Unquestionably, it will find a large use by plant physiologists, ecologists, and agronomists.

In mechanical make-up the book is uniform with the others of this series in typography, binding, etc., which insures excellent results in service. It is well illustrated and in general very pleasing in appearance. (R. W. T.)

ALFALFA GROWING IN THE UNITED STATES AND CANADA

By George Stewart, Professor of Agronomy, Utah Agricultural College. Rural Science Series, edited by L. H. Bailey; The Macmillan Co., New York. XI + 517 pp. 117 figs. 1926.

This book, like others of this Series, is written for use in the general farm library or as a secondary school text-book rather than for collegiate work in agronomy. It is not a manual, since it presents no directions for experimental study of the subjects treated; but rather is a general informational treatment of the topic in question. It is copiously illustrated with photographs of the crop in its various stages and conditions of growth and methods of treatment, line drawings of farm implements, maps of distribution, etc.

The various chapters treat of the following aspects of growing and utilizing the crop: The Increasing Importance of Alfalfa; History of Alfalfa; The Plant and its Varieties; Adaptation—Climate, Water, Soil, and Variety; Soil Improvement and Crop Rotation; Inoculation and Fertilizers; Seed-bed, Seed, and Seeding; Care of the Growing Crop and Weed Control; Irrigation of Alfalfa; Cutting and Curing Alfalfa; Hauling, Storing, and Marketing; Seed Production; Diseases, Insect, and Rodent Pests; Chemical Composition and Energy Values; and Feeding Value of Alfalfa. An extensive bibliography, covering 35 pages, and an appendix containing statistics of acreages and production of alfalfa and other forage crops in the United States and Canada, and labor requirements for producing the crop, are included. The index is well arranged and unusually complete.

The author is an enthusiastic advocate of the use of alfalfa as a farm crop. His own personal experience with it has evidently been largely in the West. On that account, he minimizes the difficulties in the curing and use of the crop which farmers in the humid East are likely to experience; and gives rather inadequate discussions of the practices which are necessary to avoid these difficulties.

The book is uniform in typography and make-up with some of the earlier numbers of the Series, having the familiar blue cloth binding and embossed-letter title arrangement. It will undoubtedly find large use for the same purposes which have been served by similar numbers of the Series in the past. (R. W. T.)

NOTES

A SIMPLE METHOD FOR COMPARING THE ACIDITY OF DIFFERENT pH VALUES

In reaction studies employing the colorimetric method, pH values are obtained at intervals of tenths pH. The pH, sometimes called the hydrogen-ion exponent or Sorensen number, is the logarithm of the reciprocal of the hydrogen-ion concentration. Consequently, in order to compare reactions, it is necessary to convert pH into normalities of hydrogen-ion. The calculation is not difficult, but requires considerable work.

A scheme sometimes used is that of Wherry in which he expresses neutrality, or pH 7, as specific acidity or specific alkalinity equal to one. Specific acidity, then, increases in multiples of 10 for each integral increase in pH value as follows:

SPECIFIC ACIDITY CORRESPONDING TO DIFFERENT pH

pH	7.0	6.0	5.0	4.0	3.0	2.0
Specific acidity	1	10	100	1,000	10,000	100,000

For intervals between integral numbers, as between pH 7.0 and pH 6.0, the corresponding specific acidities are:

pH	7.0	6.9	6.8	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0
Specific acidity	1	1.26	1.6	2.0	2.5	3.15	4.0	5.0	6.3	8.0	10.0

To obtain corresponding specific acidities between any other integral numbers, multiply these values by the specific acidity of the integer. Thus, for the range between pH 6.0 and pH 5.0 multiply the above values by 10; for the range between pH 5.0 and pH 4.0, multiply the above values by 100, etc.

This method of obtaining specific acidity is quite simple. For example, to find specific acidities corresponding to pH 5.8 and pH 5.2 subtract from pH 7.0. The differences are 1.2 and 1.8, respectively. Raise 10 to these powers. Thus $(10)^{1.2}$ is 16 and $(10)^{1.8}$ is 63, the approximate specific acidities. Comparison may now be made direct. Since 63 is approximately four times 16, pH 5.2 is four times as acid as pH 5.8.

The following scheme, however, seems even simpler for comparing concentrations of hydrogen-ion. Standard formulae for converting millivolt readings into pH values show that pH 1 has the value equivalent to 0.0592 millivolt under standard conditions. One-tenth pH, therefore, is equivalent to 0.00592 millivolt. A decrease in millivolt readings of 0.00592 or equivalent of one-tenth pH gives an increase in hydrogen-ion concentration of 1.26 times. This change to 1.26 times the acidity with each change of one-tenth pH toward the acid side is an approximate constant value.

Thus, to compare the concentrations corresponding to the pH values used above, subtract 5.2 from 5.8 which gives 6 as the number of tenth pH intervals. Then 1.26 is raised to the sixth power, *viz.*, $(1.26)^6 = 4.0$, or pH 5.2 is approximately 4 times as concentrated in hydrogen-ions as pH 5.8. To compare 5.2 with 6.8, it would be necessary to multiply the above value by 10, and similarly for other comparisons. Thus 5.2 from 6.8 gives 1.6 or 16 tenth pH intervals to reckon $= 10 \times (1.26)^6 = 40.0$.

Since the figure 1.26 is the approximate constant for increase in acidity for 0.1 pH and its log is 0.1004, these two figures can be easily remembered. To raise 1.26 to any power, it is necessary only to multiply the log 0.1004 by the power and find the antilog of this result. The only recourse to log tables, therefore, is to obtain the one value which is a direct comparison, without further calculation, of the hydrogen-ion concentrations of the two pH figures under consideration. It will assist also in making close approximations of comparisons without calculation to remember that each increment of 0.3 pH toward the acid side approximately doubles the hydrogen-ion concentration.—R. E. STEPHENSON, *Soils Department, Oregon Agricultural College, Corvallis, Ore.*

PRINCIPLES TO BE CONSIDERED IN PLANNING EXPERIMENTS WITH FERTILIZERS FOR ASPARAGUS

It is only in comparatively recent years that fertilizer experiments have been planned on the principle of feeding the plant rather than fertilizing the soil. This change in point of attack has resulted in information of much greater value to research men interested in the nutrition of plant growth. Much money and effort have been spent on studying the effect of chemicals on plant growth and in many cases reports on such experiments have been ended with the statement that, "More work is necessary before recommendations can be made." Unfortunately the "more work" is not always carried out, perhaps because the problem is too involved to give clear cut data. Experiments of this nature need not give positive results to be valuable to the research man and to be successful so far as money and effort expended on them is concerned. Consistent negative results are often of more value, but even negative results are not forthcoming in many carefully planned nutritional experiments.

Fertilizer experiments on annual plants (grain or vegetable crops) have had as their objective greater yields per acre, and have given very little attention to quality studies. If it was shown that a certain combination of fertilizers gave an economical increase in yield, the project was treated as closed. To be sure, much valuable information on the use of fertilizers has been gained even from negative experiments which has made it possible to make general recommendations as to the kind of fertilizer to use for a specific crop within rather broad limits.

But does this apply to perennial herbaceous plants? Is it possible to recommend a certain fertilizer to a grower and feel fairly certain that he will be satisfied with the results? With a few meager exceptions, it is very doubtful that this is the case. Of course it is well known that a crop needs phosphorous, potash, nitrogen, and many minor salts to make a growth commensurate with desired results as to yield and quality. Yet much of the available data show neither positive nor negative results. Why this inability to deduce application to practice?

Take asparagus as an example. For three years, the writer has been engaged in a study of conditions affecting the growth of asparagus. A study of existing literature has revealed very intangible results from the application of fertilizers. It is impossible at the present time to recommend, with any degree of confidence, what kind of a fertilizer to apply and at what time of the year to apply it. Enthusiastic reports (decidedly conflicting) from growers on the use of this or that fertilizer may be discounted by the question, "Did you leave a check?" The answer is invariably, "No."

An asparagus plant has large fleshy roots in which enormous quantities of food reserves are stored, including large quantities of sugars and asparagin. If the crown with its roots is placed in sterile sand, copiously watered, and kept at a growing temperature, the crown will send up spears until every bud on the crown has been developed. As fast as the spears are cut off, new ones will be sent up. In other words, the only material the plant needs from the soil is water and oxygen. The same principle applies to flowering bulbs grown in water and pebbles during the winter. Similarly, in the field in the spring, in a mature bed from which spears are being cut, the conditions affecting the yield of spears will be water and temperature. Too much water may be as bad as not enough, because oxygen is excluded from the roots.

College and station workers have been recommending the application of nitrogenous fertilizers in the spring before the cutting season and an occasional application during the cutting season. Some growers say it pays to do this, others are doubtful. The questions arise, do growers really get returns for labor and fertilizer?

Is this the right time to apply soluble fertilizers? On a theoretical basis, is it possible to get immediate results? Aside from the possibility of getting some increase in weight of spears through the ability of the spear to hold more water because of the presence of these salts, it is possible that the yield may actually be decreased. Perhaps the presence of salts in the soil helps to hold water for the plants, but may not inexpensive common salt (sodium chloride) do the same thing?

How may the yield be decreased? Miss Eckerson[1] has shown that sugars are necessary to reduce the nitrates in the plant, and in the case of asparagus during the cutting season these sugars must come from the storage reserves because the spears are removed before any sugar from photosynthetic activity can be supplied to the crown and roots. In other words, this sugar is taken from the reserves stored the previous year and cannot be replaced until growing stems are produced after the cutting season. If this reserve sugar is used up in nitrate reduction, there will be less to produce tissue in the spears which may in some cases reduce the number and size of the spears produced. Nelson[2] has shown in the case of alfalfa that if the young shoots are removed for hay before the late bloom stage, the plant is in danger of being killed by exhaustion because the growth is largely made at the expense of the reserves. No amount of fertilizer could save the plant, as sugar cannot be taken in from the soil and stored as reserves. It must come from leaves. If these exhausted plants were subjected to freezing temperatures they would be killed, while if they were placed under favorable growing conditions they might, by sending up very small spindly sprouts, gradually build up the root reserves. This was shown definitely by an exhaustion test on one-year-old asparagus roots, carried on by the writer. The method of killing some perennial weeds is continuous cutting to exhaust the root stalks. No amount of fertilizer in the soil will prevent these plants from dying unless there is sufficient stem growth to store reserve material in the roots.

These facts should influence fertilizer experiments with asparagus. Fertilizers, especially nitrates, must be applied in such a way and at such a time that a mass of reserve material is stored from the food synthesized in the stems and leaves. This reserve in the asparagus roots is the means of producing a maximum yield of spears. This fact must be kept in mind in taking data to show the effect of a given treatment. Thus the treatment must be given one season and the records of yields must be taken the second year; and if the second year happens to be unusually dry results may not be evident until the third year when optimum moisture conditions may exist.

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[1] ECKERSON, SOPHIA, H. Protein synthesis by plants: I. Nitrate reduction. *In* Bot. Gaz., 77: 377–390. 1924.

[2] NELSON, N. T. The effects of frequent cutting on the production, root reserves, and behavior of alfalfa. *In* Jour. Amer. Soc. of Agron., 17:100–113. 1925.

The effect of a nitrogenous fertilizer may be shown the first year in the larger, heavier, greener stems if moisture conditions are favorable. These better stems are able to store more reserve material. But to study the effect of certain kinds of fertilizers on the yield of asparagus yields should not be measured until the plant is using the material that has been fed through the roots, synthesized in the leaves, and stored in the storage organs.

If nitrate fertilizer is applied on asparagus in the early spring some of it may leach away in the open soil, and some may be taken into the plant, carried to the spears, and removed when the spears are cut; so that the only return the grower may get is a difference in quality in the spear, which may or may not be beneficial.

In a dry second season, there may be no difference in yield of spears because of insufficient water to produce normal growth and the effect of the fertilizer may not be noticeable until the third year. It is evident that there are many things that must be taken into consideration in studying the effect of a fertilizer on perennial plants. The fallacy of expecting returns the first or even second year is evident.

Theoretically, at least, soluble fertilizers should be applied on a mature asparagus field when the cutting season is finished and the plant is making stem and leaf growth so that it will take up this nitrogen and utilize it at the expense of newly formed sugars instead of the stored sugars. A fertilizer program must have as its objective the building up of a mass of reserves which will support the maximum growth. Only when the growth from this reserve is being made will there be differences between plats or units in the experiment. If the plants should store more reserve material than is used to produce the spears, it may still be impossible to see any difference from the results of the treatments of various plats.

The experiments must be guided by the growth of the aerial stems. In a young field which is not being cut, the aim must be to apply the fertilizer in such a way and at such a time that the most economical use of it can be made under the existing conditions of water and temperature, thus enabling the plant to store the maximum amount of reserves in the storage organs. The character of growth of the asparagus plant makes it difficult to tell when it will utilize nitrates and other salts to the best advantage. Until the spear has branched out and has formed some leaves it is probably drawing on the food reserve for its growth. But when it is able to manufacture its own food, another spear makes its appearance and will draw on this food reserve while the first stem is storing material in the roots. Observations on these maturing stems show that the application of nitrates makes a more vigorous, darker green growth, giving more leaf surface, and thus storing a greater amount of reserve material in the roots. This will mean larger buds and larger spears.

Measurable differences resulting from reserve material depend on the ability of the plant to make use of these reserves with the available moisture and temperature conditions during the following growing season.—V. A. TIEDJENS, *Assistant Research Professor of Vegetable Gardening, Market Garden Field Station, Waltham, Mass.*

THE SPACING OF GRAIN SORGHUMS

Data from spacing experiments at Woodward, Okla., covering four years and including Dwarf milo, Sunrise kafir, and Reed kafir, show that sorghum varieties which sucker profusely produce similar yields of grain when the distance between plants in the row varies from 6 to 30 inches. Varieties of the freely tillering class are the milos, common feterita, shallu, and Sunrise kafir. Varieties which produce few suckers show progressive reductions in yield for every successive increase in the distance between plants from 6 or 12 inches up to 30 inches. Varieties belonging in this group are Spur feterita, the kaoliangs, and probably all the kafirs other than Sunrise. These data were obtained at the Woodward Field Station, Woodward, Okla., but it seems likely that the principle involved is general in application and will hold for the entire sorghum belt.—JOHN B. SIEGLINGER, *Associate Agronomist, Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.*

AGRONOMIC AFFAIRS

EDITOR FOR AGRONOMY IN BIOLOGICAL ABSTRACTS

To fill the vacancy caused by the death of Dr. C. V. Piper, C. R. Ball, senior agronomist in charge of the Office of Cereal Crops of the United States Department of Agriculture and a former secretary and past president of this Society and formerly editor of this JOURNAL has been apppointed editor in chief for agronomy in "Biological Abstracts." M. A. McCall, of the same office, will be associate editor for crops. The first number of "Biological Abstracts" is scheduled to appear early in June, and will inaugurate reviews of literature beginning with that of 1926.

PROCEEDINGS OF WESTERN CANADIAN SOCIETY OF AGRONOMY

The proceedings of the fifth annual meeting ofthe Western Canadian Society of Agronomy, held in Winnepeg, December 29 to 31, 1924, have been published in pamphlet form by the University of Manitoba and are available upon application to the Curator of Publications of the Society, J. D. Newton, University of Saskatchewan, Saskatoon, Sask. In addition to the records of business transacted, reports of committees, etc., the report contains the following papers:

Address of President, Looking Forward.—Manley Champlin.
Classification of Canadian Wheats.—L. H. Newman.
The Amount of Variability which may be Expected to Occur in a Determination of Comparative Yields in Small Grains.—W. T.G. Wiener and R. Broadfoot.
Soil Moisture Studies at the Dominion Experimental Station, Swift Current, Sask.—S. Barnes.
Inheritance of Resistance to Black Stem Rust in Crosses Between Varieties of Durum Wheat.—J. B. Harrington.
The Milling and Baking Quality of the Wheat of Western Canada.—A. W. Alcock.
Preliminary Studies in Forage Crop Breeding.—W. Southworth.
Artificial Self-pollination of Red Clover.—L. E. Kirk.
Forage Crop Diseases.—G. R. Bisby.
Barley for Malting.—C. D. McFarland.
Malt.—G. Bailey.

SORGHUM IMPROVEMENT CONFERENCE

About 50 investigators from the Offices of Dry Land Agriculture, Cereal Investigations, and Forage Crop Investigations, and from the Bureau of Agricultural Economics of the U. S. Department of Agriculture, and from the Missouri, Nebraska, Oklahoma, Texas, and New Mexico experiment stations, including those from various branch and field stations in the Southern Great Plains and resident members of the staff of the Kansas experiment station met at Manhattan, Kansas, March 2 and 3, for a conference on sorghum improvement.

The purpose of the meeting as stated by Director Call of the Kansas Station was "to stimulate interest in sorghum research, clarify in our minds the immediate and future needs of the work, and to initiate a more or less concerted attack on those problems which the majority of workers deem to be most in need of attention."

The two days were spent in considering various phases of sorghum research, including the harvesting, thrashing, storage, and utilization; physiological, ecological, genetic, and cultural problems; classification; disease and insect control; and plat technic. The last half day was devoted to a discussion of a cooperative research program.

The principle of a definite cooperative research program was indorsed, it being pointed out that such a program would be beneficial in stimulating research, tend in a measure to prevent unnecessary duplication, and more certainly insure that the efforts of each worker and station would supplement those of others. It was recognized, however, that the successful prosecution of experimental work depends upon adequate facilities and the personal inclination and interest of the investigator and that any attempt to work out a definite program in sorghum improvement without taking these factors into consideration must result in failure.

An attempt was made to outline in a rather comprehensive way the principal problems in sorghum improvement in order to afford a perspective and to arrive at some conclusion as to which problems were most worthy of investigation. Problems mentioned for priority of attention included (1) classification and testing of varieties, (2) harvesting, thrashing, and storing, (3) physiological and ecological problems, (4) genetic problems, (5) disease and insect control, (6) utilization, and (7) cultural problems.

The conference authorized Dean L. E. Call of the Kansas Station to appoint a committee of seven members whose duty it should be to keep in touch with the different workers and to aid in carrying on the work inaugurated by the conference. The following have been appointed members of that committee: S. C. Salmon, (Chairman), Kansas State Agricultural College; H. N. Vinall, Office of Forage Crop Investigations, U. S. Department of Agriculture; J. H. Martin, Office of Cereal Investigations, U. S. Department of Agriculture; E. F. Chilcott, Office of Dry Land Agriculture,

U. S. Department of Agriculture; R. E. Karper, Texas Agricultural Experiment Station; C. P. Thompson, Oklahoma A. and M. College; and H.L.Kent, New Mexico College of Agriculture and Mechanic Arts.

S. C. Salmon, *Secretary.*

NEWS ITEM

H. L. Shantz, senior physiologist in charge of the Office of Plant Physiological Investigations of the Bureau of Plant Industry of the United States Department of Agriculture, will become head of the Department of Botany of the University of Illinois upon the retirement of Professor William Trelease from that position at the close of the present year, under the compulsory retirement rule of the University.

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METRICAL ATTRIBUTES AND THE PHYSIOLOGY OF HARDY VARIETIES OF WINTER WHEAT[1]

K. H. KLAGES[2]

INTRODUCTION

Temperature constitutes, without doubt, one of the greatest single factors affecting the distribution of plants. This is true especially with such plants that must pass through the winter in the vegetative state. Thus, Merriam (50)[3] states that "animals and plants are restricted in their northward distribution by the total quantity of heat during the season of growth and reproduction." He points out the close relationship existing between temperature and distribution of plants, yet his statement does not express the whole truth. Schimper (66) calls attention to the fact that temperature extremes are of greater importance in determining the limits of plant distribution than temperature averages for any given period. Percival (58) states that the temperature for winter wheat (*Triticum vulgare*) should not fall below—20° C. Ackerman (2) points out that the most resistent varieties of winter wheat at Svalöf, Sweden, suffered from a fall of the temperature to—18° C. Salmon (61) shows that the isotherm 10° F. for the January and February daily minimum temperature coincides well with the northern boundry of winter wheat culture. Kopper (41) points out a correlation between the polar limits of tree growth and the isotherm 10° C. for the warmest month of the year. Shreve (71) states that "the investigation of the control of plant distribution by the various phases of the temperature factor is one of the most important tasks of physiological plant geography."

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[1] A thesis submitted in partial fulfillment of the requirements for the degree of doctor of philosophy in the Graduate School of the University of Illinois. The writer wishes to express his appreciation for the helpful suggestions of Dr. W. L. Burlison of the Department of Agronomy, and of Dr. C. F. Hottes of the Department of Plant Physiology. Received for publication January 9, 1926.

[2] Assistant Professor of Agronomy, Oklahoma Agricultural and Mechanical College, Stillwater, Okla.

[3] Reference by number is to "Literature Cited," p. 562.

Low temperatures not only set the northern boundary for winter wheat production, but also cause, together with other factors, much damage even in the heart of the winter wheat producing sections. The average amount of winterkilling for the years 1900 to 1920, inclusive, was 9.8%. During the season of 1912, 20.1% of the crop was killed. In 1917, 12,437,000 acres of wheat sown in the autumn previous to the cropping season were abandoned in the spring of the year named. These figures point out the economic importance of the problem under consideration.

Under the heading of winterkilling not only plants actually killed but also those weakened or destroyed, as resulting from secondary causes, must be considered. Thus Sorauer (73) shows that frost-injured plants fall prey to and are more easily killed by fungi than sound plants.

Various methods for evaluating the degree of hardiness of the different varieties or strains have been advanced from time to time. Such standards for hardiness advocated for a given locality, however, are often found to lack universal application. Also, a given criterion for hardiness may be of value for a definite period or for a certain set of conditions only. The reason for this will become apparent upon a consideration of the various ways through which killing by means of low temperatures is brought about.

It is not the object of this paper to discuss the direct effects of low temperatures on the living cell. Numberous papers dealing with this phase of the problem can be found, *viz.*, Chandler (12), Gorke (25), Lidforss (45), Maximov (49), Mez (51), Molisch (54), Muller-Thurgau (55), Rosa (60), Salmon (62), Schander and Schaffnit (64), Wiegand (84), and others.

Three main theories are held to explain the cause of death by freezing, namely, (a) physical injury to the plant tissue, (b) desiccation of the protoplasm, and (c) chemical changes within the plant cell. Death may result from any one or a number of the above conditions depending on the characteristics of the plant, as well as on the external conditions incident to freezing. Mez's vitalistic theory of the "specific minimum" is of historic interest only.

In view of the fact that death may result from a number of causes and considering that winter wheat is grown under a wide range of climatic and edaphic conditions, it is not surprising to find that no one standard for hardiness has universal application. Even in the same locality damage to the crop may result from a different set of conditions in different seasons. When all the factors that may modify the degree of injury are taken into account, the problem of devising a usable standard for evaluating the degree of hardiness of varieties or strains under all conditions of culture becomes complex indeed.

It is the object of this paper to point out some physical and physiological properties of hardy varieties of winter wheat rather than to attempt to set up an infallible, everywhere usable, criterion for hardiness. Attention will also be given to the various phases in the development of winter wheat and to differences in the course of development of winter and spring types.

EXPERIMENTAL

RELATION OF LEAF AREA TO HARDINESS

To what extent external morphological plant structures may prove of protective value against low temperatures has long been a question.

Schaffnit (63) found no relation between external plant characteristics and ability to endure low temepratures. Schimper (66) observes that "the capacity to withstand intense cold is a specific property of the protoplasm and is quite unassisted by protective measures that are external." Kjellman (34) from observations of the plant life of polar regions came to the same conclusion. Nilsson-Ehle (57), as a result of his breeding experiments, concluded that the degree of winterhardiness of wheat stands in no definite relation to the ordinary, morphological, varietal characteristics.

In a considerable number of other investigations, however, correlations between certain obvious external properties and hardiness are reported. Thus, Storber (75) comments on the xerophytic structures of "winter leaves" of herbs. Kolkunov (40) points out the relation of xerophytic structures to hardiness in winter wheat. Salmon (62) also states that most hardy cereals are characterized by certain xerophytic structures such as narrow leaves and a prostrate habit of growth. Sinz (72) designates hardy varieties of wheat as having narrow, firm, and well-cutinized leaves. Buhlert (10) found that hardy varieties of winter rye and wheat had small leaf areas. This difference in the leaf area of the hardy and the non-hardy variety was greater in the case of the rye than in the case of the two varieties of wheat compared. Buhlert's conclusions were drawn, however, from the study of only two varieties of both rye and wheat and these were selected to represent extremes, hardy and non-hardy types. Arnin-Schlagenthin (5) points out a correlation between dwarfness and hardiness in winter wheat.

Schliephacke (67) characterizes hardy varieties of winter wheat by narrow, cuneiform leaves. He also calls attention to physiological drought as a factor causing injury. Physiological drought as stated by Salmon (62) "has never been proved to be a cause of winterkilling of cereal crops, but has long been regarded as a cause of injury to shrubs and trees." Considering, however, the evidence advanced especially by Molisch (54), and by Müller-Thurgau (55) concerning the rôle of desiccation as a cause of death in freezing, and keeping in mind the various structures associated with hardiness in the cereals as pointed out above, all of which have a marked tendency to reduce transpiration, the part played by physiological drought merits attention. Schimper (66), though not believing that external plant characteristics influence the ability of a plant to endure low temperatures, nevertheless, points out that desert plants frequently have a strong resemblance in their structure and habit of growth to those of polar regions.

The leaf area exposed by the young wheat plant no doubt constitutes the greatest factor determining the amount of water to be transpired. True, various modifications of the epidermis may affect the loss of water from the leaves, yet when comparing different varieties of wheat in this respect the amount of water transpired from the plants can be taken as a function of the surface exposed to the elements. "In a preliminary study of several varieties of winter wheat, rye, barley and oats," Salmon and assistants "found no differences in cell structure, epidermal covering, or ability to control transpiration that could be correlated with the great differences in cold-resistance known to exist." No material differences were found in the rate of loss of water from equal weights of leaves from different varieties of winter wheat in tests conducted at various times during autumn and early winter.

Table 1 shows the comparative leaf areas of nine varieties of winter wheat grown in the autumn of 1924, together with the estimated percentages of winterkilling and the yields of these varieties for the cropping season of 1923 to 1924. The winter of 1923 to 1924 was very favorable for testing the relative hardiness of the varieties grown on the Agronomy South Farm of the Illinois Experiment Station at Urbana. The yields of the different varieties grown at Urbana in 1923 to 1924 stand in direct relationship to the degree of hardiness of the respective varieties. The plants were measured on October 25, three weeks after seeding. It must be mentioned here that, due to the extremely favorable growing conditions, the plants came up in five days and grew rapidly. The respective rates of growth for these varieties will be considered later (Tables 15 and 16). The plants were very uniform. The measurements of leaf areas and the counts of the number of tillers are based on a population of 50 plants for each variety.

TABLE 1.—*Leaf areas and number of tillers of nine varieties, October 25, 1924, together with the yields and estimated percentages of winterkilling for the cropping season 1923 to 1924, at Urbana.*

Variety	Number of tillers	Leaf area in sq. mm.	Estimated precentages of winterkilling winter of 1923–24	Yield in bushels per acre season of 1924
Turkey Red....	3.90	1,832±41	0	40.3
Minturki......	3.36	2,200±45	0	46.0
Hardy Northern	4.02	1,972±39	0	42.3
Blackhull......	3.80	2,120±45	25	38.6
Mediterranean..	3.64	2,468±47	35	36.4
Fulhio........	3.80	3,072±52	38	36.4
Poole.........	3.70	2,804±61	67	25.7
Berkeley Rock..	3.54	2,248±48	75	20.9
Fulcaster......	3.96	2,636±46	78	21.1

The leaf area of the plants was determined with the aid of a planimeter (Fig. 1). The leaves of the plant whose area was to be measured were pasted on the reverse side of a thin pane of glass with the aid of vaseline. The outline of all the leaves of the plant laid side by side was then traced. By this method the total leaf area of the plant could be determined with one circumscription of the tracer point of the instrument. When this process was carried on in the laboratory it was found necessary to add paraffin to the vaseline in order to hold down the leaves properly, the amount for best results being dependent on the temperature of the room. All figures on leaf areas reported on in this paper refer to the surface exposed by one side only.

From Table 1 it is seen that the hardy varieties, with the exception of Minturki, have a relatively small leaf area. The leaf area of Minturki is larger than that of Blackhull and almost as large as that of Berkeley Rock. There is a great difference in the hardiness of these varieties when grown at Urbana. The characteristic high rate of growth of Minturki during the early phases of development is in part responsible for its greater leaf area. When the dry weights of 100 plants later in the season, December 16, are considered (Table 16), it is seen that the weight for Minturki is appreciably lower than that for Berkeley Rock; however, it is still higher than for Blackhull.

Berkeley Rock, a non-hardy variety at Urbana, but having a much smaller leaf area than the other non-hardy varieties given in Table 1, when grown at the Michigan Experiment Station has shown itself to be winterhardy. It is considered more hardy there than either Fulhio or Poole, varieties with extremely large leaf areas. The Montana Experiment Station also considers Berkeley Rock more hardy than Fulcaster, Mediterranean, or Poole.

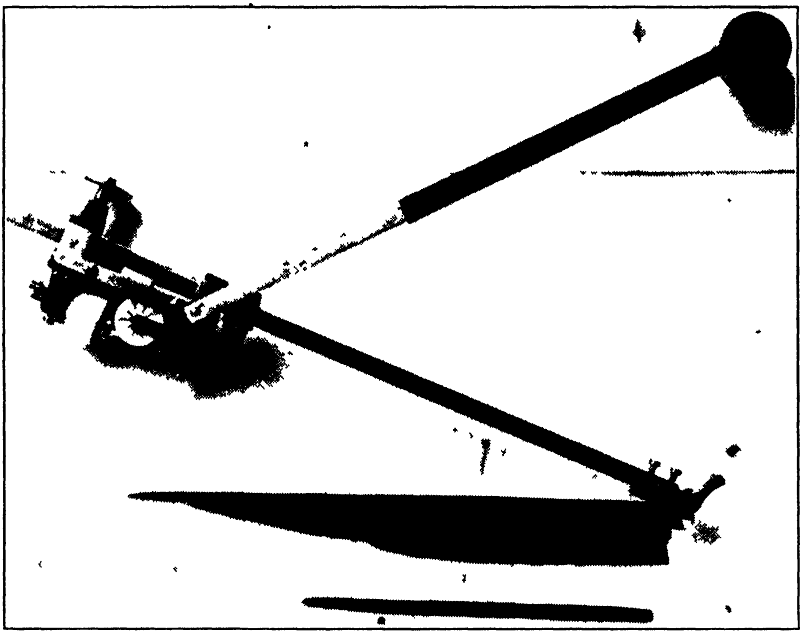

FIG 1.—Showing method of measuring the area of leaves of young plants.

Minturki has shown itself to be very hardy at Urbana. At many stations in the more humid sections of the country, or in sections where evaporation during the winter is low, it has been found even more hardy than Turkey Red. In regions dry during the winter and early spring, and especially in regions with a combined condition of dry climate and high wind velocity at these periods of the year, as in the central and northern Great Plains area, Minturki has yielded less than Turkey Red. This is brought out in Table 2. The figures given in Table 2 were compiled from data presented by Clark and Martin (13). The yields of Minturki and Turkey Red are compared at those stations of the central and northern Great Plains area where these two varieties were grown. In case more than one strain of Turkey Red was grown at a given station the yields of all strains for the years of comparison are given.

At all of the stations mentioned Turkey Red has outyielded Minturki for the period of comparison. The differences in the yield of these two varieties is due, to a large part, to differences in winter survival. Observations at the Colorado Experiment Station at Fort Collins have shown Minturki to be less hardy there than Turkey Red.

TABLE 2.—*Comparative yields of Minturki and Turkey Red in the central and northern Great Plains area.*

Station	Variety	C. I. No.	Yield per acre, bushels		
			1920	1921	1922
Fort Hays, Kans......	Minturki	6155	22.7	21.2	7.1
	Turkey	1558	25.8	27.2	10.5
	Turkey	5592	26.5	26.9	12.0
	Turkey	6472	26.7	25.0	11.9
	Turkey	6613	29.5	26.8	9.9
Akron, Colo..........	Minturki	6155	18.1	7.0	9.1
	Turkey	1571	21.7	15.3	12.7
Archer, Wyo..........	Minturki	6155	——	16.6	13.0
	Turkey	1571	——	12.0	21.2
Dickinson, N. D......	Minturki	6155	——	4.4	33.5
	Turkey	1571	——	3.4	40.3

The larger leaf area of Minturki, causing it to be more subject to desiccation, together with its characteristic habit of growth, may throw some light on its behavior in those regions where climatic conditions are conducive to a high rate of evaporation. Bonnier's (9) work, showing that plants lose water more rapidly at high than at low elevations, has application here, since the stations enumerated in Table 2 are all located at an altitude of 2,000 feet or more.

The above warrants the conclusion that leaf area, though not an absolute index of hardiness at Urbana, nevertheless, is a factor worthy of consideration in the selection of hardy types of winter wheat. In semi-arid or in arid regions, where desiccation of the plants is of greater consequence than in humid sections, a closer relation is to be expected between leaf area exposed by the plants and hardiness. Yet, even in these sections, the plant may be injured or killed due to factors other than desiccation. The intricate mechanism of the plant cell is subject to injury from a multitude of conditions, desiccation of the protoplasm being only one of them.

It has frequently been reported that hardy varieties of winter wheat are characterized by dark green leaves. This was found through observation to hold true in a general way only. The relation is not absolute. Both Turkey Red and Hardy Northern have dark green leaves. The color of the leaves of these two varieties is more intense than the color of the leaves of Minturki or Blackhull. The color of the leaves of the less hardy varieties given in Table 1 is of a considerably lighter shade than that of the hardy varieties. Westermeier (83) points out that varieties of wheat with dark green leaves have a smaller leaf area than those with lighter colored leaves. The intensity of the color is determined by the number of chloroplasts per cell or per unit area. With a more intense color and consequent higher rate of assimilation, as shown by Haberlandt (27) and Plester (59), there is also an increase in the rate of assimilation per unit area exposed by the plant. This would put the small-leaved, dark green varieties at a marked advantage under conditions where exposure of large leaf area to the elements is detrimental to the plants.

CORRELATIONS OF WIDTH OF SEED LEAVES, AREA OF SEED LEAVES, AND WIDTH OF WIDEST FOLIAGE LEAVES WITH TOTAL LEAF AREA

It is apparent that a correlation between some obvious and easily measurable trait is of value in differentiating between varieties or strains of small, medium, or large leaf areas. From measurements of the width of leaves of plants in the field it appeared that a correlation between certain attributes of the seed leaf, such as width or area, and total leaf areas of the plants might be found.

Due to the fact that the sides of the seed leaves are nearly parallel to each other, their widths can be easily and accurately measured. The seed leaf can be readily detected by its straight lines, greater thickness, and blunt apex. Percival (58) points out that the "characteristic and easily recognizable shape of this leaf greatly assists in the determination of the number of separate plants in a crowded row of seedlings in the field."

In order to find whether or not a correlation exists between characteristics of the seed leaf and total leaf area, 54 varieties of winter wheat were grown on a bench in the greenhouse at a temperature of 60° to 65° F. This temperature was found to be very conducive to the growth of winter wheat. A somewhat lower temperature, 55° to 60° F., is recommended for the early period of growth, since it will lead to the production of stockier plants. Three representative plants of each variety were measured. This gave a total population of 162 plants for use in the correlation table. It may be mentioned that in order to remove the personal element a student was instructed to select the plants used. Plants were measured in the three-leaf stage and again one week later when they had from three to six tillers (Fig. 2).

The writer is indebted to D. W. Robertson of the Colorado Experiment Station for a large number of the varieties of winter wheat used in this phase of the investigation.

A very pronounced correlation is evident in all instances (Table 3). Due to the fact that the width of the seed leaf is more readily determined, and since it is as reliable a criterion of the total leaf area of the plants as is the area of the seed leaf, it offers the more usable index.

TABLE 3.—*Summary of correlations of width as well as area of the seed leaf and total leaf area of plants in the three-leaf and tillering stages. Plants grown in the greenhouse.*

Stage of development	Value of "r"—width of seed leaf and total leaf area	Value of "r"—area of seed leaf and total leaf area
Three-leaf	0.833±0.016	0.884±0.012
Tillering	0.820±0.017	0.843±0.015

Attention is called to the constancy of the width of the seed leaf as compared to the increase of the total leaf area from the three-leaf to the tillering stage (Table 4).

TABLE 4.—*Seed leaf measurements, width and area, as compared to total leaf area in the three-leaf and tillering stages.*

Stage of development	Mean for width of seed leaves in mm.	Mean for length of seed leaves in mm.	Mean for area of seed leaves in sq. mm.	Mean for total leaf area in sq. mm.
Three-leaf....	4.18±0.04	92.31±0.64	361±6	1,307±22
Tillering	4.11±0.03	88.56±0.68	331±5	2,535±40

The width of the seed leaves remained practically constant, while an actual decrease resulted in the case of their areas, due mainly to a decrease in length. This decrease in the size of the seed leaves is to be expected since they function only during the early stages of growth. In most cases the seed leaves are found dead in the spring on plants grown in the field according to Hays and Boss (29). The width of the widest foliage leaves of these plants increased in the same period of time from 4.19 to 5.16 mm., while the length of these leaves increased from 123.40 to 147.35 mm.

The plants used for the correlation so far reported were grown in the greenhouse. It was considered of value to find how close this correlation would hold for plants grown in the field. It was thought advisable also to find how close the relation of the width of seed leaf as well as the width of the widest foliage leaf and total leaf area would hold within a given variety, the data so far reported having been obtained from the study of plants from 54 varieties taken in aggregate. The plants from which the data given in Tables 5 and 6 were secured were the same as reported on under the discussion of the relation of leaf area to hardiness. The figures are based on a population of 50 plants for each variety.

TABLE 5.—*Width of seed leaf, widest foliage leaf, total leaf area, and number of tillers for varieties grown in the field in the autumn of 1924.*

Variety	Number of tillers	Width of seed leaves in mm.	Width of widest foliage leaves in mm.	Total leaf areas in sq. mm.
Turkey Red	3.90	3.55±0.04	5.08±0.05	1,832±41
Minturki	3.36	3.69±0.04	6.02±0.05	2,200±45
Hardy Northern	4.02	3.55±0.04	5.43±0.05	1,972±39
Blackhull	3.80	3.80±0.04	5.56±0.05	2,120±45
Mediterranean	3.64	4.34±0.04	6.21±0.07	2,468±47
Fulhio	3.80	4.74±0.04	6.72±0.05	3,072±52
Poole	3.70	4.83±0.05	6.39±0.05	2,804±61
Berkeley Rock	3.54	4.22±0.04	6.28±0.05	2,248±48
Fulcaster	3.96	4.08±0.04	6.03±0.04	2,636±46

In Table 6 are given the values of the correlations between the width of the seed leaf as well as the width of widest foliage leaf and total leaf area for the respective varieties mentioned in Table 5.

TABLE 6.—*The value of "r" for the correlation of the width of seed leaf as well as the width of the widest foliage leaf, and total leaf area for each of the given varieties. Plants grown in the field.*

Variety	Value of "r"—width of seed leaf and total leaf area	Value of "r"—width of widest foliage leaf and total leaf area
Turkey Red	0.719±0.046	0.696±0.049
Minturki	0.752±0.045	0.726±0.045
Hardy Northern	0.766±0.040	0.628±0.058
Blackhull	0.767±0.039	0.703±0.048
Mediterranean.	0.787±0.036	0.646±0.056
Fulhio.	0.661±0.054	0.586±0.063
Poole	0.767±0.039	0.728±0.045
Berkeley Rock.	0.771±0.039	0.544±0.067
Fulcaster	0.604±0.061	0.618±0.059
Varieties assembled	0.800±0.012	0.741±0.014

Most varieties show a high correlation with respect to both of the characters. In all cases, except one, and here the difference is not significant, the correlation between the width of the seed leaf is higher than between the width of the widest foliage leaf. Since the width of the first is more readily and more accurately determined, the seed leaf measurement furnishes, without doubt, the better index of leaf area.

Before bringing to a close this phase of the investigation, it will be advisable to consider the variability of the three-leaf characteristics dealt with in Table 5. The coefficients of variability for these factors are given in Table 7.

TABLE 7.—*Variability of factors compared, namely, width of seed leaves, width of widest foliage leaves, and total leaf areas, in plants grown in the field.*

Variety	C. V. for width of seed leaf	C. V. for width of widest foliage leaf	C. V. for total leaf area
Turkey Red......	10.72±0.83	10.65±0.82	23.25±2.08
Minturki........	10.47±0.91	8.19±0.55	21.32±1.87
Hardy Northern..	11.95±0.94	9.47±0.64	20.74±1.81
Blackhull........	11.82±0.93	10.21±0.79	22.03±1.95
Mediterranean....	10.65±0.83	11.31±0.88	19.81±1.71
Fulhio..........	9.75±0.66	7.05±0.48	17.59±1.48
Poole	10.60±0.82	7.61±0.51	22.72±2.02
Berkeley Rock. ..	9.85±0.67	8.69±0.59	22.55±2.01
Fulcaster........	9.04±0.61	7.69±0.52	18.47±1.57
Varieties assembled	15.47±1.27	12.24±0.97	26.35±2.44

In all the varieties except one, Mediterranean, the variability of the width of the seed leaf is greater than that of the width of the widest foliage leaf. However, the intervarietal variability of the width of the foliage leaf is greater than that of the width of the seed leaf. The standard deviation for the former is 2.71 as compared to 1.64 for the latter. This indicates that the width of the seed leaf is of special value for use in selection within a variety. Thus Blackhull, a selection from Turkey Red, differs in respect to both the width of the seed leaf and total leaf area, as well as in degree of hardiness, from the original.

RELATION OF WIDTH OF SEED LEAF TO HARDINESS

The relation of leaf area to hardiness has been discussed. The high correlation existing between the width of the seed leaf and total leaf surface exposed by the plant has also been pointed out. Table 8 gives a direct comparison of the width of the seed leaf and the hardiness of several varieties. The figures for the width of the seed leaves are based on a population of 170 plants for each variety. The leaves were measured on November 2, 1923, four weeks after the date of seeding.

TABLE 8.—*Width of the seed leaf of varieties, estimated percentages of winterkilling, and yields in the autumn of 1923.*

Variety	Width of seed leaf in mm.	Estimated percentage in winterkilling	Yield in bushels
Beloglina........	2.76±0.02	—	——
Turkey Red......	2.79±0.02	0	40.3
Malakof 5–460....	2.96±0.02	2	43.3
Gladden.........	3.18±0.02	27	37.4
Red Wave.......	3.43±0.02	—	——
Red Cross.......	3.65±0.02	10	39.1
Mediterranean....	3.87±0.02	35	36.4

Due to the less favorable growing conditions in the autumn of 1923, the plants were not so far advanced as in 1924. The plants in 1923 were in the three-leaf stage at the time the measurements were taken; in 1924 they had from three to four tillers.

Since two of the varieties reported on in Table 8, Beloglina and Red Wave, were not included in the variety test at Urbana in the year 1923 to 1924, data on the percentage of winterkilling or yield can not be given for them. From data given by Clark and Martin (13) it is seen that the winter survival of Beloglina in the dry areas of the western United States compares favorably with that of strains of Turkey wheats reported on. Red Wave is known from past performance at Urbana to be non-hardy.

In Table 9 is shown the relationship of the width of the seed leaf in the autumn of 1924 to hardiness for the varieties previously mentioned.

TABLE 9.—*Width of seed leaves of varieties in the autumn of 1924, together with the estimated percentages of winterkilling and yields for the year 1923 to 1924.*

Variety	Width of seed leaf in mm.	Estimated percentage of winterkilling	Yield in bushels
Turkey Red......	3.55±0.04	0	40.3
Hardy Northern..	3.55±0.04	0	42.3
Minturki.......	3.69±0.04	0	46.0
Blackhull........	3.80±0.04	25	38.6
Fulcaster........	4.08±0.04	78	21.1
Berkeley Rock....	4.22±0.04	75	20.9
Mediterranean...	4.34±0.04	35	36.4
Fulhio..........	4.74±0.04	38	36.4
Poole...........	4.83±0.05	67	25.7

Tables 8 and 9 show that the three hardiest varieties enumerated have the narrowest seed leaves. Even Minturki (Table 9) falls among the three varieties with narrow seed leaves. However, the difference between the width of the seed leaf of Minturki and Blackhull is not significant. The varieties under consideration in 1923, as well as in 1924, can not be separated on the basis of width of seed leaves into medium or non-hardy classes. Red Cross (Table 8) is comparatively hardy at Urbana, yet it has a wide seed leaf. Fulcaster (Table 9), though less hardy than Mediterranean or Fulhio at Urbana, has a smaller width of seed leaf than those two varieties.

The study of the relation of width of seed leaves to hardiness leads to the same conclusion as did the investigation of the relation of leaf area to hardiness. The width of the seed leaf, though not an absolute index of hardiness of a variety or strain, nevertheless offers a reliable index of the leaf area of the plants under consideration and is of value in the selection of hardy types of winter wheat in so far as the magnitude of the leaf surface exposed by the plants stands in relationship to hardiness. The relation of leaf area to hardiness, as has been previously pointed out, is dependent to a large degree on environmental conditions incident to freezing of the plants.

It is of value at this point to consider the variability of the width of the seed leaf of the several varieties above referred to. Table 10 gives the coefficients of variability of the width of the seed leaves of the respective varieties measured in the autumn of 1923 and 1924. The figures for 1923 are based on a population of 170, while those for 1924 are based on only 50 individuals of each variety.

TABLE 10.—*Variability of the width of seed leaves of varieties measured in 1923 and 1924.*

Variety	Coefficient of variability, 1923	Coefficient of variability, 1924
Mediterranean..	10.57±0.39	10.65±0.83
Red Wave.....	12.26±0.39	———
Red Cross.....	12.34±0.39	———
Malakof 5–460..	12.48±0.39	———
Gladden.......	13.26±0.39	———
Beloglina......	13.73±0.39	———
Turkey Red....	13.90±0.39	10.73±0.83
Fulcaster......	———	9.04±0.61
Fulhio.........	———	9.75±0.66
Berkeley Rock..	———	9.85±0.66
Minturki......	———	10.47±0.81
Poole.........	———	10.60±0.82
Blackhull......	———	11.82±0.93
Hardy Northern	———	11.95±0.94

The degree of variability of the width of the seed leaves among the different varieties reported on in Table 10 is quite constant, especially when the differences in the means for the respective varieties are taken into consideration. This small and constant variability permits the utilization of a rather small population for determining this character. Engledow and Wadham (19) call attention to the striking constancy of the length of the seed leaf of barley (*Hordeum distichum*) under different conditions of growth.

HABIT OF GROWTH

Distinct differences in habits of growth can be detected between varieties of winter wheat which may be classified as prostrate, semierect, and erect (Figs. 2 and 3). The physiological significance of these habits of growth becomes apparent from the standpoint of amount of material exposed to the elements by each type.

Hardy varieties of winter wheat are commonly believed to have a recumbent habit of growth, according to Salmon (62), Summerby

(77), and Schmidt (68). This is generally true, yet some notable unconformities prevent the utilization of this varietal characteristic as an absolute criterion for hardiness. Kanred, for instance, has a more recumbent habit of growth than Turkey Red. Minturki grows

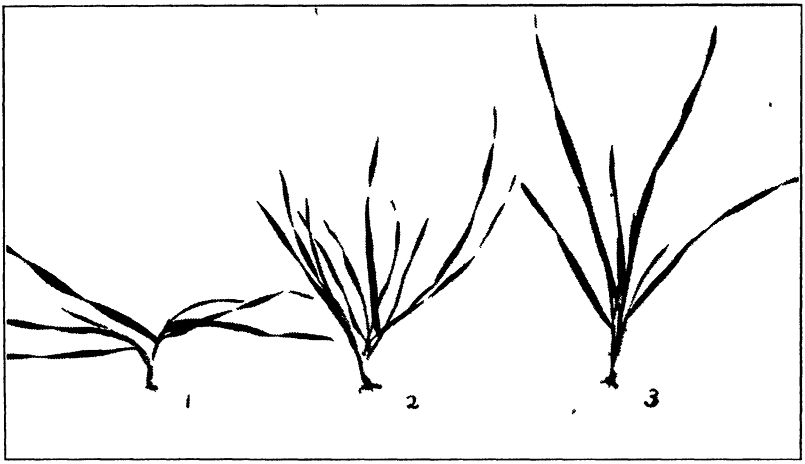

FIG 2 —Difference in habits of growth, stage of plants at time of correlation of area and width of seed leaf and total leaf area

1, Kanred, prostrate habit of growth; 2, Red Russian, semi-erect habit of growth; 3, Trumbull, erect habit of growth

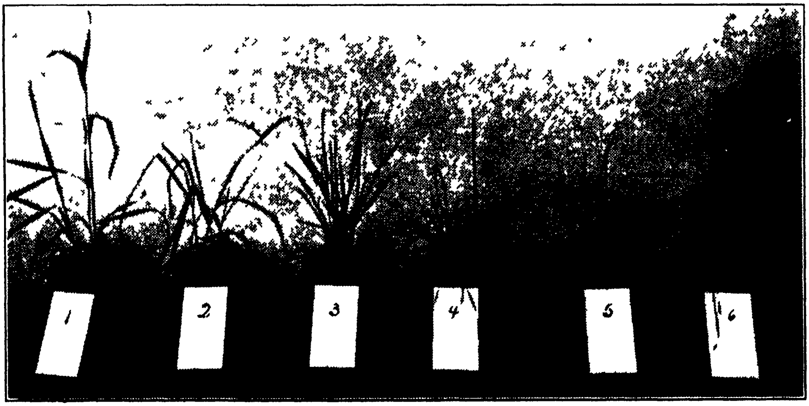

FIG. 3.—Relative difference in habits of growth of winter wheat and spring wheat. Planted in greenhouse Feb. 16, photograph taken May 16.

1, Marquis; 2, Red Wave; 3, Dawson's Golden Chaff; 4, Red Russian; 5, Minturki; and 6, Turkey Red.

semi-erect. There is no doubt that both of these varieties are more hardy than Kanred. Blackhull is less hardy than Turkey Red, yet it has the same recumbent habit of autumn growth. Mediterranean, known to be semi-hardy, has a tendency to produce semi-erect to prostrate plants, while Dawson's Golden Chaff, also semi-hardy, grows very erect.

Again it can be said that varieties of wheat with a very erect habit of growth are, as a rule, non-hardy. But this statement must also be qualified. Dawson's Golden Chaff and Red Cross both grow very erect, yet they are quite hardy, though not as hardy as the Turkey wheats. An erect habit of growth is a better indicator of lack of resistance than is a recumbent habit of growth an indicator of hardiness.

Some varieties have a more erect habit of growth during their early phases of development than later in the season. Minturki is a good example of this type. Notes on growing habits are best taken during early tillering, the varietal differences being greatest at that time. The relative differences between varieties are far more pronounced when the plants are grown in the greenhouse than when grown in the field. The tendency for erect growth is especially accentuated.

A relation of habit of growth to weight and leaf area in the three-leaf and tillering stages is shown in Table 11. The plants from which these data were taken are the same as those used in the correlation of seed leaf characteristics and leaf area reported on in Table 3. The plants were grown in the greenhouse.

TABLE 11.—*Relation of habit of growth to weight and leaf area of plants in the three-leaf and tillering stages.*

Habit of growth	Number of varieties	Weight per plant in grams			Leaf area per plant in sq. mm.			Number of tillers
		Three-leaf stage	Tillering stage	Percentage increase	Three-leaf stage	Tillering stage	Percentage increase	
Prostrate	11	0.0254	0.0547	115	935	2,084	120	4.18
Semi-erect	18	0.0314	0.0585	86	1,222	2,245	84	3.72
Erect	24	0.0375	0.0603	61	1,526	2,957	94	3.39

The prostrate varieties have both a lower weight as well as a smaller leaf area than the varieties with the semi-erect and erect habits of growth. The differences in the surface exposed to the elements by these three classes is significant. However, the rate of increase of both factors from the three-leaf to the tillering stage is greater as the recumbent habit of growth is approached. This is due to the fact that a larger number of tillers are produced by the low-growing varieties when grown in the greenhouse. It was observed that tillering of plants grown in the greenhouse began earlier in the case of the prostrate than in that of the erect-growing varieties. This is not the case in the field, as will be shown in Table 12.

Profuse tillering has often been associated with hardiness, according to Fruwirth, et al (22), Schmidt (68), and Carlton (11). Barulina (6), however, found no such relation. In Table 12 are given the number of tillers for nine varieties counted early in the season, October 25, three weeks after seeding, and again two weeks later, November 8. The first count is based on 50, the second on 100 plants, per variety. The plants were grown in the field.

TABLE 12.—*Relation between tillering and hardiness.*

Variety	Number of tillers, Oct. 25	Number of tillers, Nov. 8
Turkey Red	3.90	9.84 ±0.13
Minturki	3.36	8.09 ±0.11
Hardy Northern	4.02	9.40 ±0.16
Blackhull	3.80	9.67 ±0.11
Mediterranean	3.64	11.37 ±0.14
Fulhio	3.80	10.13 ±0.16
Poole	3.70	10.09 ±0.17
Berkeley Rock	3.54	7.88 ±0.12
Fulcaster	3.96	10.45 ±0.18

It is very evident from Table 12 that there is no relation whatsoever between the number of tillers produced by varieties in the autumn and hardiness. Grantham (26) shows that the number of tillers produced by winter wheat is more dependent on conditions of culture than on varietal characteristics.

RATE OF GROWTH IN RELATION TO HARDINESS

"Any treatment materially checking the growth of plants increases cold resistance," says Rosa (60). Orchardists have long recognized the importance of dormancy, reduced activity, as a protective measure against frost injury. Schaffnit, (63) points out that death resulting from the precipitation of the cell proteids is likely to occur, especially in spring, under conditions where the plant is suddenly checked during active growth.

It is generally known that plant protoplasm contains a larger amount of vegetative water in the active than in the quiescent state. Numerous investigators have called attention to the fact that in many cases cold resistance in woody as well as in herbaceous plants is associated with low water content, notably Ackerman and Johnson (3), Chandler (12), Newton (56), Seelhorst (70), Sinz (72), and others. It has also been demonstrated by Newton (56), Rosa (60), and Strausbaugh (76) that dormant plants or plants having been exposed to low temperatures retain their water with greater tenacity than rapidly growing plants. Frost resistance is increased by the accumulation of reserve materials in the cell, according to Lidforss (45) and Müller-Thurgau (55). According to Hedlund (31) such an increase in reserve material takes place when the growth of the plant is discontinued while assimilation still proceeds. Growth in this case is taken as increase in mass which, though not an infallible measure of growth, offers the best general method of comparing the relative activity of green plants.

From the above it would appear that hardy varieties of winter wheat should show a slower rate of growth than non-hardy varieties. This was found by Hedlund (31) to be generally true. Buhlert (10) also found that his hardy variety of both wheat and rye had a slower rate of growth than the two non-hardy varieties of these cereals. Arnin-Schlagenthin (5) indicates a possible correlation between a slow rate of growth and dwarfing of plants in the autumn and hardiness. Wallén (80) points out a negative correlation between temperature in autumn and yield of winter wheat in southern Sweden as contrasted to a positive relation between these same factors in the northern part of the country. In the first case an excessive autumn growth of the crop proved to be detrimental. Further north, however, the temperature was not high enough to permit rapid growth.

In a number of herbaceous plants hardy types have been found by Buhlert (10) and Fruwirth, et al (22) to have a smaller root system than non-hardy types. Livingston (46) states that "in wheat the variation in growth of tops is correlated with the number and length of lateral roots." Moeller (53), in his studies on the dwarfing of oats (*Avena sativa*) and of *Bromus mollis*, found that the absolute number and weight of the roots was smaller in the case of the dwarfed plants, but that, relatively, the root systems of these plants were more extended than those of the normal plants. Consequently, it is only to be expected that if non-hardy varieties produce a greater top growth they would have a more extended root system.

Schliephacke (67) recommends the selection of winter wheat for a strong root system. The importance of a strong root system to hardiness and more particularly to reduced injury resulting from heaving has been overemphasized. It is hard to conceive of a root system in such plants as the cereals strong enough to withstand the tremendous force incident to alternate freezing and thawing. The relative development of the root system is of less importance in determining whether or not a plant will survive than a plant character instrumental in reducing the loss of water. This would apply especially to plants that have been partly heaved out of the soil.

In order to determine the respective rates of growth of a hardy and a non-hardy variety of wheat in the greenhouse, Turkey Red, known to be hardy, and Red Wave, a non-hardy variety, were grown on brown silt loam in 4-gallon containers. For the sake of comparison a lot of Marquis was also grown. The weights of a lot of Turkey Red exposed to outside temperatures from November 8 to November 22, and again for two days, December 13 and 14, are also given in Table 13. The weights are based on 10 plants per container. One-half of the plants on the exposed lot of Turkey Red were killed at the time of the second exposure. All lots were planted on October 18, 1923.

TABLE 13.—*Rates of growth of a hardy and a non-hardy variety of winter wheat in the greenhouse compared to the rate of growth of Marquis and a lot of Turkey Red subjected to low temperatures.*

Date	Weight of Red Wave in grams	Weight of Turkey Red in grams	Weight of Turkey Red (exposed) in grams	Weight of Marquis in grams
1923				
Oct. 25	0.067	0.063	0.066	0.042
Nov. 8	0.307	0.295	0.226	0.238
Nov. 22	0.902	0.893	0.291	0.824
Dec. 6	1.727	1.179	0.574	1.175
Dec. 20	2.495	2.145	0.786	1.448
1924				
Jan. 3	4.828	3.371	0.709	1.830
Jan. 17	7.579	2.354	1.209	2.525
Jan. 31	10.396	3.407	1.635	3.038
Feb. 14	12.526	5.616	2 883	3.945
Feb. 28	15.779	6.204	2.135	4.489
Mar. 13	18.971	8.142	3.161	4.849
Mar. 27	20.223	10.350	8.469	5.938

Red Wave shows a decidedly higher rate of growth than Turkey Red. The factors concerned in the last two columns of Table 13 will be considered later.

In the autumn and winter of 1924 to 1925 rates of growth in the greenhouse of three hardy and three non-hardy varieties of winter wheat were determined. Three varieties of spring wheat were grown for the sake of comparison. The plants were grown in 1-gallon containers, six plants per container. All lots were planted on October 21. The bi-weekly weights of these plants are given in Table 14.

The two hardy varieties Turkey Red and Hardy Northern show a low rate of increase. Minturki, though growing less rapidly than Fulcaster or Red Wave, grows almost as fast as Berkeley Rock. The difference in the weights of Red Wave and Turkey Red is as large as in the previous year. In view of the lack of consistency in the behavior of the other varieties it must be concluded that the rate of growth of a variety or strain in the greenhouse can not be taken as an index of its hardiness. Attention is called to the fact that the increase in weight of the respective varieties, be they winter or spring wheats, is continuous.

TABLE 14.—*Rates of growth in the greenhouse of hardy and non-hardy varieties of winter wheats and of spring wheats, dry weights, in grams, of six plants.*

	Hardy varieties			Non-hardy varieties			Spring wheats		
Date	Turkey Red	Minturki	Hardy Northern	Fulcaster	Berkeley Rock	Red Wave	Wisconsin Wonder	Marquis	Preston
1924									
Nov. 11	0.27	0.28	0.26	0.37	0.31	0.32	0.23	0.26	0.29
Nov. 25	0.82	0.81	0.68	0.83	0.89	0.73	0.58	0.57	0.60
Dec. 9	1.43	1.56	1.54	1.94	1.61	1.61	1.28	1.08	1.49
Dec. 23	2.23	2.93	2.34	3.35	2.92	2.61	2.70	2.33	2.12
1925									
Jan. 6	3.88	4.49	3.90	4.95	5.46	4.93	5.67	4.49	5.21
Jan. 20	7.28	6.56	8.20	10.73	8.88	7.70	6.93	8.11	7.85
Feb. 3	9.19	11.90	9.68	15.29	12.68	14.20	12.12	11.00	11.63
Feb. 17	11.88	20.17	15.31	18.95	18.18	17.50	20.57	16.83	19.94
Mar. 3	18.87	20.37	20.79	26.00	22.00	25.57	30.15	22.15	26.54
Mar. 17	20.38	28.92	21.16	29.10	28.40	32.11	27.89	28.56	39.00
Mar. 31	28.05	38.42	27.91	32.06	35.00	33.00	35.90	35.95	42.71
Apr. 14	34.00	42.30	35.20	36.90	37.76	36.65	31.25	43.93	45.00

The respective increases in the dry weights of 25 plants of nine varieties grown in the field were determined in the autumn and winter of 1924 to 1925. The plants were cut at the surface of the ground at intervals stated in Table 15.

Realizing the danger of basing conclusions on so small a number of plants as indicated in Table 15, it was considered advisable to determine the dry weights of the varieties previously mentioned using larger numbers. Table 16 gives the dry weights of 100 plants at the dates indicated.

Tables 15 and 16 show that the hardy varieties produce less material when grown in the field in the autumn, from October 4 to December 13, than the non-hardy varieties. Of the non-hardy varieties Berkeley Rock produces considerable less material than Poole or Fulcaster. What has previously been said about the hardiness of Berkeley Rock should be kept in mind. The weights of 1,000 kernels of Berkeley Rock and Mediterranean give evidence that the weight of the seed is not the primary factor determining the amount of material produced.

The hardy varieties cannot, however, be distinguished from the medium-hardy on the basis of the amount of material produced in the

TABLE 15.—*Dry weights in grams of 25 plants of hardy, medium-hardy, and non-hardy varieties of winter wheat grown in the field.*

	Hardy varieties			Medium-hardy varieties			Non-hardy varieties		
Date	Turkey Red	Minturki	Hardy Northern	Blackhull	Mediterranean	Fulhio	Poole	Berkeley Rock	Fulcaster
1924									
Oct. 11	0.12	0.15	0.12	0.10	0.17	0.16	0.15	0.13	0.18
Oct. 18	0.66	0.71	0.65	0.61	0.84	0.79	0.74	0.69	0.84
Oct. 25	1.73	2.23	2.00	1.84	2.64	2.40	2.38	1.95	2.39
Nov. 1	3.63	4.32	3.55	3.66	4.31	4.52	4.03	4.00	4.37
Nov. 8	7.40	8.70	7.70	9.10	9.60	10.70	10.50	8.80	11.70
Nov. 15	10.90	12.55	12.40	12.54	13.75	17.74	16.26	15.35	17.20
Nov. 22	11.60	13.53	13.34	14.00	18.00	18.18	18.52	15.64	19.61
Nov. 29	13.64	13.86	13.73	14.60	18.93	20.15	21.25	18.46	20.81
Dec. 6	13.74	15.02	13.81	14.70	19.20	22.05	22.39	19.05	21.48
Dec. 13	14.44	15.34	14.00	14.82	20.94	22.43	22.52	19.85	21.75
1925									
Feb. 7	13.18	13.10	13.24	12.56	15.90	16.58	15.62	16.43	15.80
Feb. 21	13.32	13.68	13.71	13.46	16.03	16.95	16.04	16.05	16.05
Mar. 7	13.75	14.61	16.00	15.26	16.42	17.37	16.52	16.10	16.56
Mar. 21	18.08	19.72	22.15	17.95	17.75	18.08	17.72	17.40	19.12
Apr. 4	29.18	33.92	31.16	25.58	32.18	27.26	27.61	33.31	32.22
Total weights from Oct. 11 to Dec. 13, in grams	77.86	86.41	81.30	85.97	108.38	119.12	118.74	103.92	120.33
Weight of 1000 kernels in grams	29.40	30.96	27.48	31.36	40.36	35.84	32.88	34.20	36.80

TABLE 16.—*Dry weights in grams of 100 plants of hardy, medium-hardy and non-hardy varieties of winter wheat grown in the field.*

	Hardy varieties			Medium-hardy varieties			Non-hardy varieties		
Date	Turkey Red	Minturki	Hardy Northern	Blackhull	Mediterranean	Fulhio	Poole	Berkeley Rock	Fulcaster
1924									
Nov. 8	37.78	41.51	40.95	40.34	47.64	56.41	48.28	45.73	50.35
Dec. 16	70.68	84.93	72.40	77.38	90.26	106.93	102.57	92.93	105.15
1925									
Feb. 14	62.00	——	62.00	——	——	——	——	60.40	68.58
Mar. 12	64.63	75.10	65.78	66.35	72.10	76.52	71.31	71.18	76.07

autumn. Minturki shows a more rapid rate of growth than Blackhull. Attention has already been called to the rapid rate of growth of Minturki. On the other hand, the dry weights of 25 plants are always higher for Blackhull than for Turkey Red or Hardy Northern, yet the respective differences are not great enough to warrant the drawing of decisive conclusions from the data available

The medium-hardy varieties cannot be separated from the non-hardy on the basis of rate of autumn growth. Mediterranean produced as much material as Berkeley Rock, and Fulhio produced more material than any other variety grown.

TABLE 17.—*Percentage reduction in the dry weights of 100 plants in the field from December 16 to February 14 and to March 14.*

Variety	Percentage reduction from Dec. 16 to Feb. 14	Percentage reduction from Dec. 16 to Mar. 12	Remarks, March 12
Turkey Red....	12.28	8.56	Small number of dead leaves
Minturki......	——	11.57	Small number of dead leaves
Hardy Northern	14.36	9.14	Small number of dead leaves
Blackhull......	——	14.25	Consid'r'ble number of dead leaves
Mediterranean..	——	20.12	Large number of dead leaves
Fulhio........	——	28.43	Leaves and stems killed back
Poole.........	——	30.48	Leaves and stems killed back
Berkeley Rock..	35.00	23.40	Leaves and stems killed back
Fulcaster......	34.78	27.66	Leaves and stems killed back

Since the weight of a plant in autumn is closely associated with its leaf area, the conclusions reached relative to the connection of leaf area to hardiness apply here. The reduction in the dry weights of 100 plants (Table 17) from December 16 to February 14 and to March 12 is directly proportional to the amount of material exposed to the elements rather than in direct relation to the degree of hardiness of the respective varieties. Attention is here called to the differences in the average heights of 100 plants of Turkey Red and Minturki for three consecutive weeks, October 11 to October 25. The means for the heights of Turkey Red expressed in mm. for the dates given are 66.8 ±0.7, 132.4 ±0.9, and 153.5 ±1.1, respectively, as compared with 77 ±0.8, 162.4 ±0.9, and 185.5 ±1.1, respectively, for Minturki. These figures emphasize the differences in the growing habits of these two varieties.

DEVELOPMENT OF WINTER AND SPRING WHEAT

Schmidt (68) gives the following phases for the development of spring and winter cereals. Spring cereals pass through the (a) germination and tillering, (b) shooting, (c) flowering, and (d) ripening stages; while winter cereals pass through successive periods of (a) germination and autumn tillering, (b) vegetative awakening and spring tillering, (d) shooting, (e) flowering, and (f) ripening.

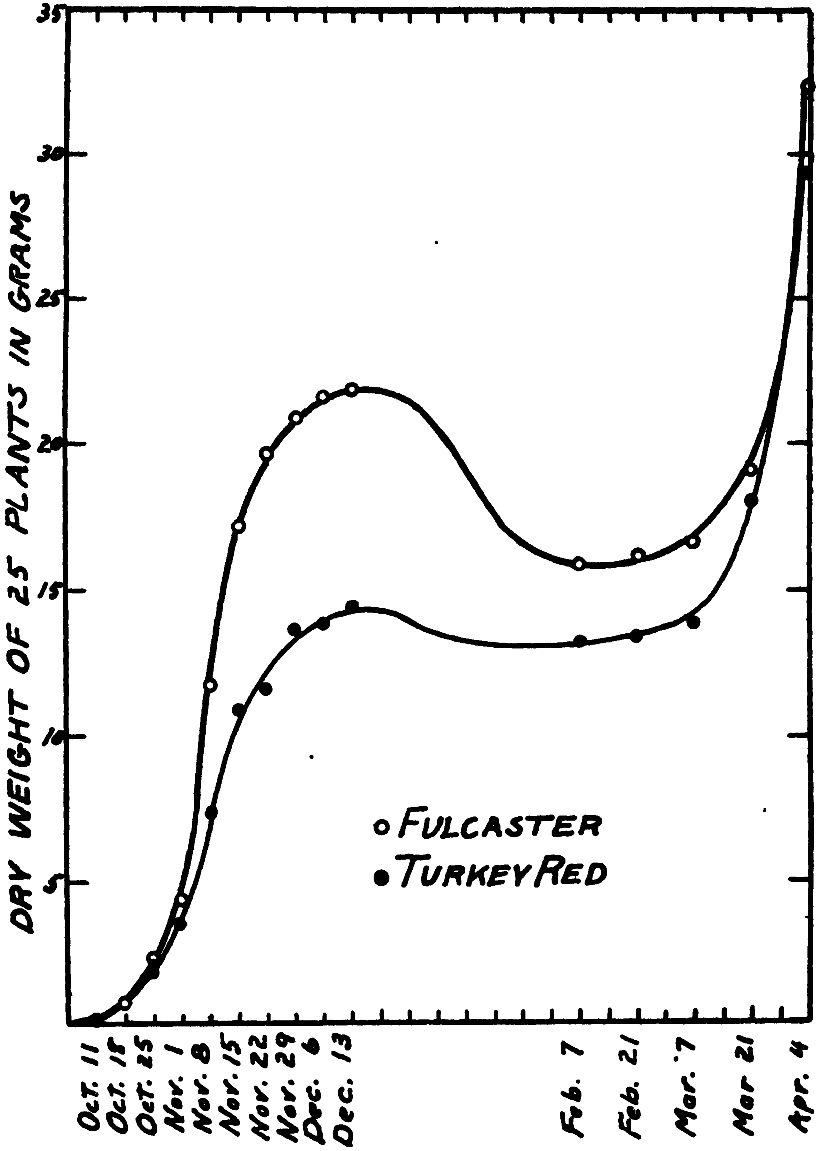

FIG. 4.—Growth of winter wheat in the field, dry weights of 25 plants.

The question at once arises as to whether the differences in the cycles of development of these two groups are due to internal, inherent properties of the plant, or whether they result from the external factors of the environment.

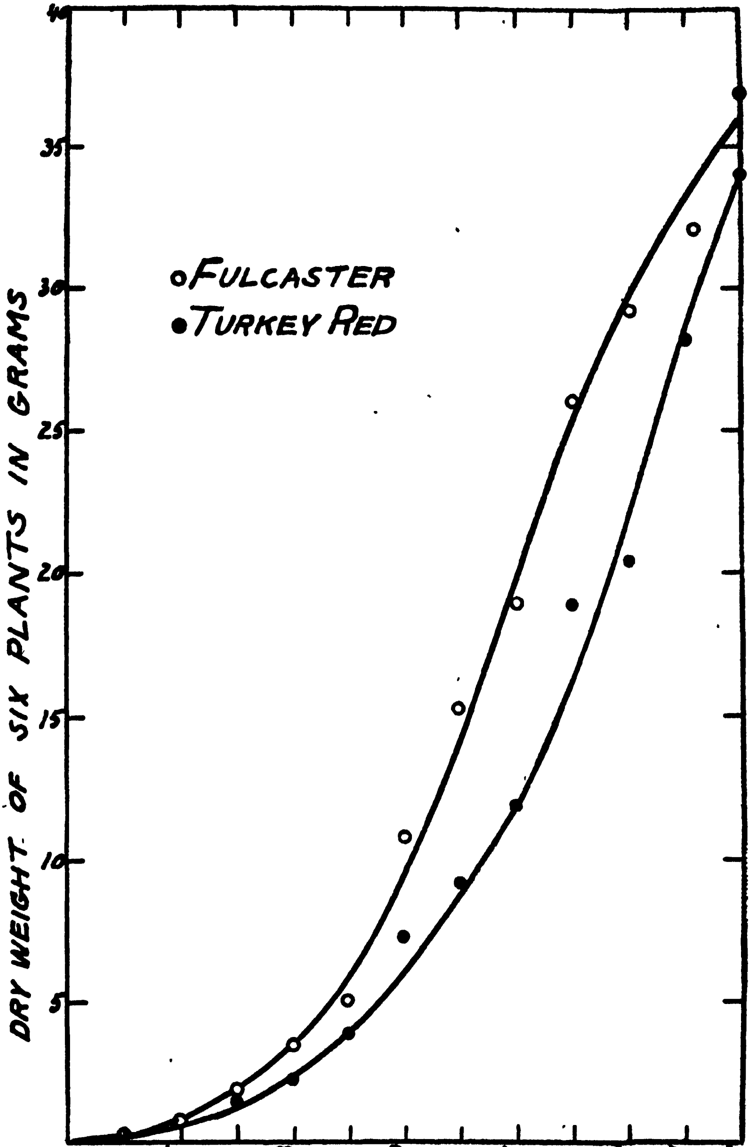

FIG. 5.—Growth of winter wheat in the greenhouse, dry weights of six plants grown in 1-gallon containers.

The above phases of development, so far as winter wheats are concerned, are well supported by the work of Weaver, et al (82), as well as by the results of successive weights of plants grown in the field (Tables 15 and 16). A period of rapid growth and of increase in the number of tillers follows germination. The rate of growth is slowed down with advent of lower temperatures as the season progresses. During the coldest part of the winter an actual loss of material results (Table 17). A period of rapid growth follows the coming of higher temperatures in the spring (Fig. 4). Using Scharfetter's (65) terminology the "vegetation rhythm" follows the "climate rhythm." Two growth curves are evident from the data of weights of field plants (Table 15) the limiting factor in the first being temperature and in the second advance in differentiation.

When the rates of growth of winter wheat grown in the greenhouse are considered (Tables 13 and 14), a marked difference from the course of development as ordinarily followed in the field becomes apparent There is one continuous curve with no indication of a period of dormancy (Fig 5).

There is no material difference in the form of the growth curves of winter and spring wheats when grown in the greenhouse. This shows that the rhythm in development as displayed by winter wheat when grown in the field is enforced and not voluntary.

It has been shown that the length of life of a plant, that is, whether it will behave as an annual, overwintering annual, biennial, or perennial, using Acherson's classification as given by Krause (44), is determined mainly by external factors, according to Costantin (17), De Vries (18), and Hildebrand (32). The normal course of development as ordinarily observed in nature or in cultivated plants is not, as stated by Klebs (35), determined from start to finish by the inherent constitution of the species. Klebs considers the constellation of external factors with which the plant comes in contact as constituting the forces determining the course of development. Consequently, under changed external conditions an enforced deviation from the previously followed course becomes evident.

It must not be overlooked that in reality the external factors with which the plant comes in contact modify certain internal conditions in the plant so that the resulting behavior is not due directly but only indirectly to the reaction with the environment. Thus, the time of flowering as pointed out by Mobius (52) is markedly influenced by external conditions, especially by light and moisture relationships. Fischer (20) and Loew (48) point out the importance of an abundant production of carbohydrate materials to flowering. Kraus and Kraybill (43) are more specific in showing that the behavior of a plant with regard to vegetative growth and reproduction depends on the proportion of available carbohydrates to nitrogen. There is in plants, then, in relation to factors determining their course of development much the same condition as Loeb (47) has indicated in his tropism theory of animal conduct. Thus Loeb states and presents evidence to the effect that "motions caused by light or other agencies appear to the layman as expressions of will and purpose on the part of the animal, whereas in reality the animal is forced to go where carried by its legs. For the conduct of animals consists of forced movements."

Winter wheats planted in the greenhouse at various dates during the autumn and winter were successfully grown to maturity without the intervention of the period of low temperature and dormancy commonly believed necessary. Two varieties of winter wheat, Red Wave and Turkey Red, planted on October 19, 1923, headed out on

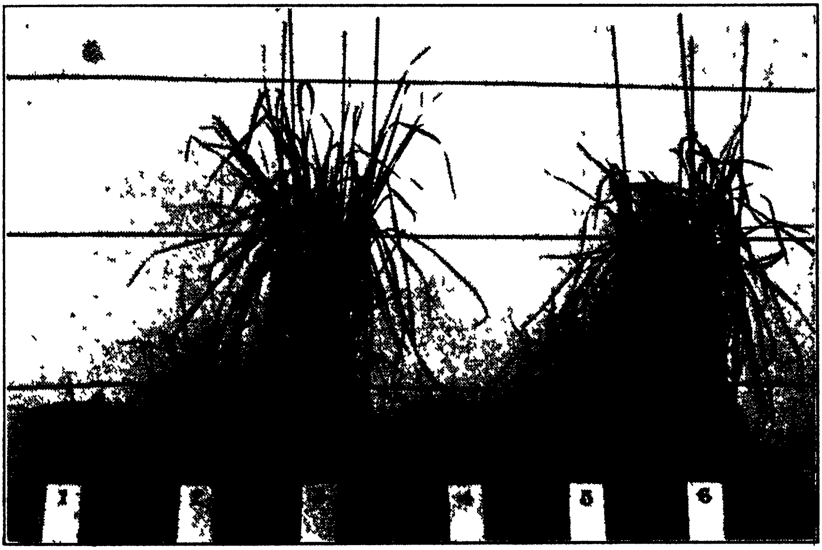

FIG. 6.—Effect of exposure to low temperature, growth in the greenhouse, and growth in the greenhouse with the aid of artificial light. Planted Oct. 21, photograph taken Dec. 26, 1924.

1, Turkey Red exposed headed April 10; 2, Turkey Red grown in greenhouse headed April 10; 3, Turkey Red grown in greenhouse with aid of artificial light headed March 24; 4, Minturki exposed headed April 2; 5, Minturki grown in greenhouse headed April 2; 6, Minturki grown in greenhouse with the aid of artificial light headed March 12.

April 17 and May 6, respectively. A lot of Turkey Red exposed to freezing temperatures for a period of two weeks and again later in the season for two days headed out on the same day as the un-exposed lot. Marquis planted at the same time as these two winter wheats did not head out until May 20, more than a month later than Red Wave. More will be said about this later. The successive increase in the weights of these plants is shown in Table 13.

The effect of exposure to heading was again put to test in the autumn of 1924 when the length of exposure was extended, lasting from the time of seeding, October 21, to December 17. Nine varieties were included in this experiment. Fig. 6 shows two of the varieties nine days after the exposed plants were returned to the greenhouse as compared to plants continually in the greenhouse, and such grown with the aid of artificial light. At the end of the period

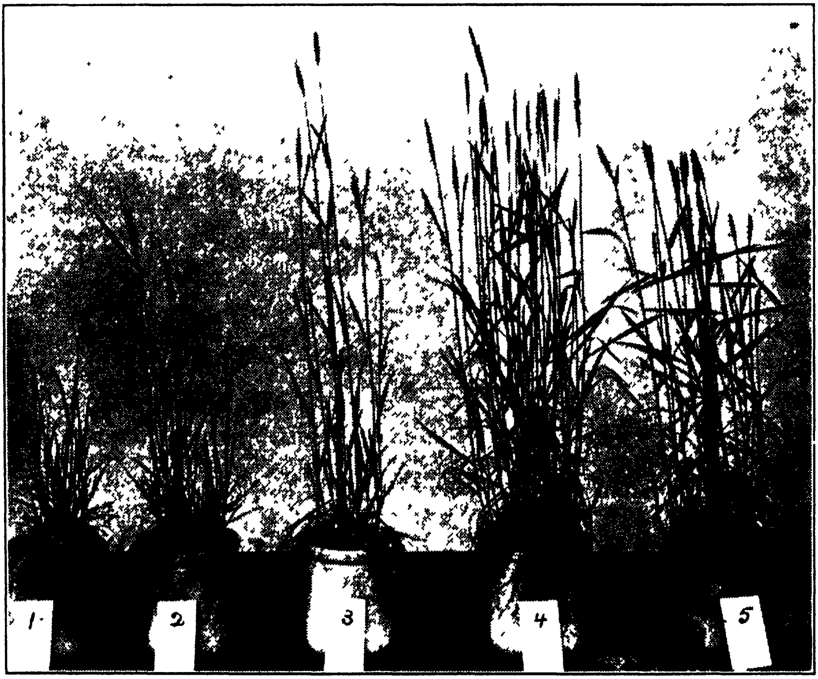

FIG. 7.—Heading of winter wheat without the intervention of a period of low temperature, showing the difference in the behavior of different varieties. Planted Dec. 18, photograph taken May 12.

1, Beloglina headed out May 22; 2, Turkey Red headed out May 12; 3, Mediterranean headed out May 4; 4, Minturki headed out April 29; 5, Marquis (check) headed out April 20.

of exposure the plants had but three leaves. After being brought into the greenhouse they tillered and grew rapidly. In the case of all varieties the exposed lot headed out on practically the same date as the unexposed plants. This proves definitely that exposure to freezing temperatures is not essential to culm and flower formation.

Fifty-four different varieties of winter wheat were planted in 1-gallon containers, six plants per container, on December 18, 1923. These plants were grown at temperatures of 60° to 70° F. They were kept in the greenhouse from the time of planting to maturity. All varieties headed out between April 28 and May 24. Fig. 7 shows typical plants of this lot. The difference in the behavior of the separate varieties is brought out. Attention is called to the fact that there is but little difference in the date of heading of this lot as compared with the varieties planted in October. Five varieties of spring wheat planted at the same time as these winter wheats headed out between April 15 and May 2.

Another lot of the same 54 varieties of winter wheat referred to above was planted in flower pots, one plant per pot, on February 16, 1924. Of these, 24 varieties headed out between June 21 and August 15. Normal plants were produced. The varieties that did not head out were killed by the high temperature prevailing in the greenhouse during the latter part of April and in May. Four of five varieties of spring wheat planted at the same time headed out between May 23 and June 12.

It will be of interest to note the variation in time required from the date of planting till heading of the several varieties of winter wheat as well as of spring wheats planted at different dates. This is shown in Table 18.

TABLE 18.—*Variations in time required from planting to heading of winter and spring wheats groun in the greenhouse when planted at different dates, shouing the number of varieties heading in the period of time indicated.*

Type of wheat	Date of seeding	Number of days from planting to heading														
		95	100	105	110	115	120	125	130	135	140	145	150	155	160	180
Winter	Dec. 18									4	6	17	11	12	4	
Spring	Dec. 18						1	1	1	1	1					
Winter	Feb. 16							1		3	7		5	3	4	1
Spring	Feb. 16	1	1	1		1										

Winter wheat when sown early in spring will undergo normal development if sown early enough in the season. Table 19 gives the yields of six varieties of winter wheat as compared with Marquis. The yields were taken from 4-foot rows. The primary object of this experiment was not to determine the yields of the respective varieties, but to find whether or not they would head, and for that reason too much emphasis should not be given to the yields reported. Twenty-four varieties were sown on March 1, 1924. All of them headed out normally, the yields of the six best varieties being given in Table 19. The plants were normal when compared with Marquis.

TABLE 19.—*The yields of six varieties of winter wheat sown in the field March 1, 1924, compared with Marquis.*

Variety	Weight of grain in grams	Weight of straw in grams
Kanred	48.5	220.0
World's Champion	48.0	192.7
Malakof 5-460	46.8	203.2
Turkey Red	40.0	193.4
Minnesota Reliable	39.5	174.9
Dawson's Golden Chaff	26.3	118.5
Marquis (Check)	44.0	180.0

Plants sown two weeks later, March 15, succumbed to rust. The plants sown on March 1 had some exposure to low temperatures, yet this exposure did not give the plants the incentive or build up in them the materials essential for heading as one would be led to believe from the work reported by Fruwirth (21), Gassner (24), or Seelhorst (69). That such is not the case is seen from the behavior of winter wheats grown in the greenhouse without the intervention of a period of low temperature.

In view of the differences in the cycles of development of winter wheats grown with and without the intervention of a period of low temperature the periodic behavior of this plant when grown in the field cannot be considered as resulting from internal factors only. In this case dormancy is determined by external factors and cannot be regarded as by Küster (cited by Klebs, 38) to be autogenous. One would hesitate to agree with Clements (14) that "changes or conditions connected with the resting period become fixed habits, owing to their constant recurrence." Even Clements' statement that "rhythm appears to depend as much or even more upon the habitual development of the plant as on the physical factors of its habitat" may rightly be questioned. Schimper (66) in his account of periodic phenomena of tropical vegetation states that "internal causes are mainly or solely responsible for the alteration of rest and activity in a nearly uniform climate." Klebs (37), however, not only doubts Schimper's statement as to the necessity of a period of dormancy in tropical plants, but also presents evidence to show that such periods of quiescence are not the result of internal, hereditary factors but are produced by external conditions, either climatic or edaphic in nature. Under proper nutrition tropical plants were grown in the greenhouse for a number of years without the intervention of a period of dormancy.

Klebs (36) comes to the conclusion that in the last analysis all variations from the commonly observed course of development are produced through changes in the environment which allow the internal potentialities of the organism to come to expression. In order to determine the limits of variability, or as Detto calls it the "potentielle Variationsbreite," it is necessary to expose a plant to a great diversity of external conditions. In the case under discussion the respective behavior of winter wheat grown in the greenhouse and in the field is, no doubt, determined by the difference in environment; yet what has previously been said concerning the indirect effect of external factors should be kept in mind.

What has been said above should not be interpreted to mean that there is no difference between the genetic constitution of spring and winter wheats. Genetic studies of these two types have thrown considerable light on the nature of winterhardiness, as witness Hays and Garber (30), Nilsson Ehle (57), and Waldron (79). The greatest difference between the two types is that under all conditions, except where some factor such as lack of light causes some physiological disorder, the winter wheats remain longer in the vegetative stage than the spring wheats (Table 20). The effect of low intensities of light on inhibiting the growth of spring wheat is brought out in Table 13. Spring wheats when grown in the greenhouse with or without the aid of artificial light will not tiller as much as, or remain in the tillering stage as long as winter wheats. Kőrnicke (42) states that both spring and winter wheats undergo a pause in the course of development. This pause is short in the case of the former and long in the case of the latter. Cooper (15), as a result of his studies on the inheritance of winter and spring habit in winter x Marquis crosses, concludes that Marquis possesses an inhibitor for winter habit. The fact that spring types cannot be selected from pure lines of winter wheats is substantiated by Fruwirth (21) who offers further evidence of a genetic difference between the two types. Killer (33), as well as Vavilov (78), reports success in the selection of spring types from winter varieties only in those cases where the former were present *a priori*.

With the exception of Fruwirth, et al (22), all investigators consulted on the inheritance of winter x spring crosses report the spring habit as dominant. Correns (16) in a cross of *Hyocyamus niger annuus* x *H. niger biennis* found the biennial habit of growth completely dominant over the annual.

The ratios secured in the segregation of the F_2 generation differ as given by the various investigators. From data reported in this paper it is apparent that the expression of spring or winter habit is dependent on a rather specific interaction with the environment. The differences in the time of heading of winter wheat, when sown at the same date or at different dates (Table 18 and Fig. 7) no doubt offer an explanation for the lack of agreement in the ratios realized by different investigators. The advance of the season as brought out by Gassner (24) and as shown in Table 18 is an important factor in determining the time required from planting to heading. Climatic conditions, soil, and cultural differences are stated by Blaringhem (8) to produce differences in the segregation of characters of barley hybrids in F_2. No doubt, all these factors exert their influence on the segregation of populations of winter x spring crosses. It is only reasonable to expect that they would have an influence on the

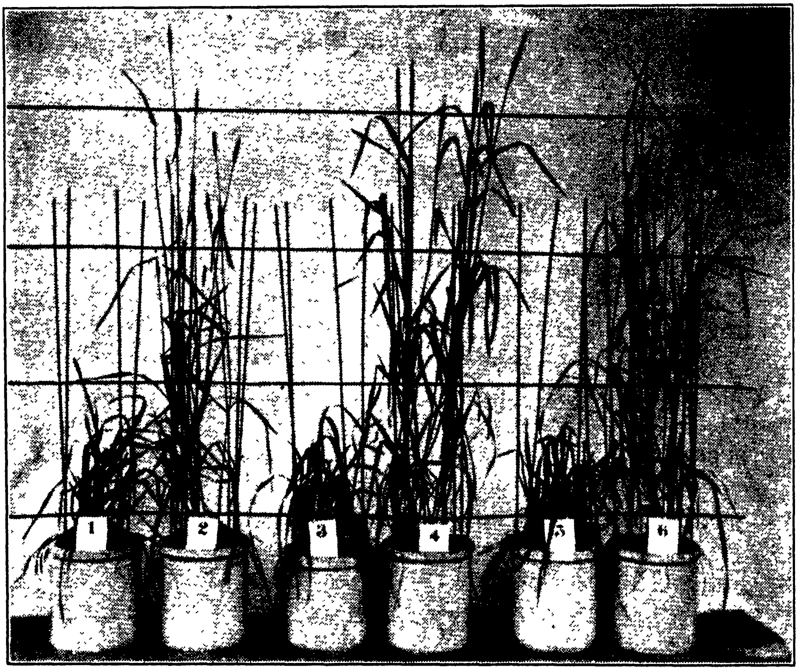

FIG. 8.—Effect of artificial illumination on the development of spring wheat. Wheat planted Oct. 21, put under light Nov. 19, photograph taken Dec. 26. 1, Wisconsin Wonder without artificial light; 2, Wisconsin Wonder with artificial light; 3, Preston without artificial light; 4, Preston with artificial light; 5, Marquis without artificial light; 6, Marquis with artificial light.

ratios secured. Even the personal element is a factor of importance in determining these ratios where the classes are not definitely delineated. Certain winter wheats, such as Red Wave or Dawson's Golden Chaff, display a growing habit approximating that of a typical spring variety (Fig. 3).

Baur (7) sums up the relation of the genetic constitution to the expression of characters of an organism in an admirable manner by stating that only a certain, specific reaction method towards the external environment is inherited. Perceptible characters are but the result of this interaction with the particular constellation of external conditions under which the individual has developed.

THE ROLE OF LIGHT IN THE DEVELOPMENT OF SPRING AND WINTER WHEAT

It has been shown that exposure to low temperatures is unessential for the normal course of development of winter wheat. Exposure to low temperatures or an enforced period of dormancy is not instrumental in building up materials in the plant necessary for culm and flower formation. The importance of light to the building up of "flower-forming substances" or, more specifically, its importance to the accumulation of a reserve carbohydrate supply has already been referred to. Numerous investigators, such as Fischer (20), Loew (48), and Möbius (52) have shown the importance of a carbohydrate reserve in the plant to fruiting. Möbius has shown that an increased temperature has a favorable effect on flower production. He states, however, that in the tropics especially, the higher temperatures may often be more than counterbalanced by the influence of high or excessive moisture. Möbius, though not aware of it, provided evidence for the later work of Kraus and Kraybill (43) on the "carbohydrate—nitrate relationship" in plants to reproduction and growth.

During the early phases of the investigation it became evident that light was an important factor in determining the course of development and especially the time of shooting and flowering in both winter and spring wheats. Adams (4), while this investigation was in progress, demonstrated that the time required from seeding to flowering in winter wheat and rye can be materially reduced by the use of electrical illumination.

In the autumn of 1923 it was noticed that Marquis was more sensitive to a low intensity of light such as prevails during late autumn and winter than two varieties of winter wheat with which its rate of growth was compared (Table 13). This condition was noticed whenever winter and spring wheats were grown together. Spring wheats grown with a deficiency of light developed chlorosis when the leaves of the winter wheats showed no indication of it. The comparative susceptibility to a deficiency of light was again well brought out in the autumn of 1924 (Table 14). The spring wheats at that time showed a rate of growth comparing more favorably with the growth of the winter wheats than in the previous year due to the better natural illumination. However, even in the autumn of 1924 the effect of a series of cloudy days was very apparent. The leaves of the spring wheats assumed a yellowish green color and developed light spots, while those of the winter wheats retained their dark green color.

TABLE 20.—*Differences in dates of heading of spring and winter wheats grown with and without the aid of electrical illumination.*

Variety	Lot 1 planted Oct. 21, put under light Nov. 19				Lot 2 planted and put under light Nov. 22			
	With light		Without light		With light		Without light	
	Date of heading	Number of days from planting to heading	Date of heading	Number of days from planting to heading	Date of heading	Number of days from planting to heading	Date of heading	Number of days from planting to heading
Spring Wheats								
Wisconsin Wonder	Dec. 12	52	Jan. 27	98	Dec. 27	35	Mar. 16	144
Preston	Dec. 20	60	Mar. 29	159	Jan. 5	44	Apr. 20	181
Marquis	Dec. 22	62	Apr. 2	163	Jan. 9	48	Apr. 18	179
Kota					Jan. 7	46	Apr. 23	184
Winter Wheats								
Minturki	Mar. 7	137	Apr. 2	163	Apr. 2	131	Apr. 24	185
Red Wave	Mar. 12	142	Apr. 6	167	Apr. 6	135	Apr. 26	187
Turkey Red	Mar. 24	154	Apr. 10	171	Apr. 8	137	May 1	192
Hardy Northern					Apr. 4	133	Apr. 29	190

To prove that light was the factor limiting the growth of spring and winter wheats in the greenhouse, several varieties of each were grown with the aid of artificial illumination. The lights used were 500-watt, nitrogen-filled tungsten lamps. The lights were on from 5 P. M. to 8 A. M. Table 20 shows the difference in the date of heading produced by exposure to the artificial light. Two lots of plants were used. Lot 1 was planted in the greenhouse on October 21 and exposed to the light November 19. These are shown in Fig. 6 (winter wheats) and Fig. 8 (spring wheats). Lot 2 was grown under illumination from the time of seeding, November 22.

It is evident from Table 20 that spring wheats respond more rapidly to artificial illumination than winter wheats. This is shown both by the shorter period of time required by them for heading as well as by the greater difference in the number of days required from planting to heading when the plants were grown with or without the aid of electrical illumination.

Harvey (28) reports of successfully growing spring cereals and vegetables under the continuous influence of artificial light. It is difficult, as brought out by Klebs (39), to secure an artificial source of light equal to sunlight in intensity or composition. Were it possible to devise a light more nearly approaching, or perhaps even surpassing in intensity or favorable composition, that of sunlight, the differences shown in Table 20 would, no doubt, have been even greater.

The above gives evidence of the existence of photo-critical periods in both winter and spring wheats. Certain quantities of light are essential for the normal uninterrupted development of the plants, the spring wheats being more exacting in their light requirements than the winter wheats. However, the photo-critical periods here referred to apply to the amount of light and not to a specific "length of day" as referred to by Garner and Allard (23) or by Wanser (81) in his report on photoperiodism in wheat.

SUMMARY

Studies were conducted on certain physical and physiological properties of winter wheat with the object of determining the degree of association existing between them and winterhardiness. Attention was also given to a study of factors concerned in the development of winter wheat and to the relative behavior of spring and winter varieties.

Most hardy varieties of winter wheat have a comparatively small leaf area in autumn. Leaf area, though not an absolute index to hardiness at Urbana, nevertheless is a factor worthy of consideration in the selection of hardy types of winter wheat. In semi-arid or in arid regions, where desiccation of plants is of greater consequence than in humid regions, a closer relation is to be expected between leaf area exposed by the plants and hardiness.

Close and constant correlations were found to exist between area of the seed leaf, width of the seed leaf, width of widest foliage leaf, and total leaf area of the plant. Due to the fact that the width of the seed leaf is most easily and accurately determined, it offers the best criterion of leaf area. The value of "r" for the correlation of width of the seed leaf and total leaf area in the tillering stage in plants grown in the greenhouse was 0.843 ±0.015. The correlation of the same

factors for plants grown in the field gave a value for "r" of 0.800 ±0.012.

Measurements of widths of seed leaves are of value in the selection of hardy types of winter wheat in so far as the magnitude of the leaf area exposed by plants stands in relationship to hardiness.

Variations in habits of growth do not stand in absolute relationship to hardiness. An erect habit of growth is a better indicator of lack of resistance than is a recumbent habit of growth an indicator of hardiness.

The amount of tillering of a variety in autumn gives no indication of its hardiness.

Hardy varieties of winter wheat show a less rapid rate of growth in the field in autumn than non-hardy varieties. However, due to specific varietal characteristics the amount of material produced by the several varieties does not stand in direct proportion to their degrees of hardiness. Since the weight of a plant in autumn is closely associated with the extent of its leaf area, the conclusions relative to the connection of leaf area to hardiness apply here.

The rhythm in the development as ordinarily observed in the growth of winter wheat is an enforced rhythm. Low temperatures and low intensities of light constitute the limiting factors in the growth of winter wheat in autumn. The behavior of winter wheat grown in the greenhouse, and especially the behavior of plants grown in the greenhouse with the aid of electrical illumination, precludes the autogenous explanation for the occurrence of a period of dormancy.

Exposure to low temperatures is unessential to the normal development of winter wheat.

Winter as well as spring wheats are quick to respond to the application of artificial illumination. Spring wheats are more specific in their light requirements than winter wheats.

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NEW METHODS WITH CHECK PLATS[1]

C. K. McCLELLAND[2]

With the reduction in size of plats and increase in replication in variety testing as practiced today, the use of check plats and the adjusting of yields is not very important. But with the larger plats necessary for fertilizer, cultural, or rotation tests, with the few replications possible, it is important to know the correct value of each of the check plats. Much work has been done on the subject of check plats and their relation to experimental error and many methods of using them have been tried. The main difficulty has been to arrive at their true value.

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[1] Contribution from the Department of Agronomy, University of Arkansas, Fayetteville, Ark. Reserch Paper No. 38, Journal Series, University af Arkansas. Read by W. H. Sachs at annual meeting of Southern Agricultural Workers at Atlanta, Ga., February 3, 1926. Received for publication March 6, 1926.

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In the direct uncorrected adjustment of yields by means of check plats four assumptions must usually be made. First, it must be assumed that the yields of both check and test plats are the correct yields for the given plats. In all early tests, such reasoning appears, but the application of the probable error concept has shown the fallacy of this and various methods attempting to correct it have been tried.

The second assumption is that changes from check plat to check plat are gradual or progressive, whether the fertility is increasing or decreasing. No method of correction for this assumption was available until recently when Richey (4)[3] brought out his method of adjustment of plat yields according to their regression on a moving average.

The third assumption is that seasonal conditions exert a like influence on all varieties or treatments. Salmon (5) called attention to this source of error and Stadler (6), using Red Rustproof and Kherson as a double check, also proved the falsity of the idea.

It is well known that in dry seasons nitrogenous fertilizers exercise great influence at the expense of other elements, and that in wet seasons phosphoric acid shows superiority. Deep plowing by increasing reservoir capacity, under certain conditions, shows superiority over other methods, in other seasons it shows inferiority. It may be said then that assumptions of this sort are false. There is no method of correction. Averaging over a considerable period as shown later is the only method.

The fourth assumption is that there is correlation between test and check plats, which often is, but often may not be, true since difference in location and difference in seasons may exert different influences on plats.

Richey (4) says that correlation is less with more distance between checks, or in his own words, "with only one-third to one-fifth the number of plats as checks * * * the assumption is even more arbitrary."

In determining the normal or theoretical yield of intervening plats, that is the yield which would have been obtained had the intervening plats been given the same treatment as the check plats, Stockberger

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[3] Reference by number is to "Literature Cited," p. 575.

(8) has used several formulae and shown that none of them were of much value in reducing error. Those he used were:

$$(1)\qquad \frac{c_1 + c_2 + c_n}{n} = (c) = N. \qquad (N = \text{normal yield})$$

$$(2)\qquad \left\{\begin{array}{l} (\tfrac{2}{3}\, c_1 + \tfrac{1}{3}\, c_2) = N \text{ for plat A.} \\ (\tfrac{2}{3}\, c_2 + \tfrac{1}{3}\, c_1) = N \text{ for plat B, etc.} \end{array}\right.$$

$$(3)\qquad \tfrac{1}{2}\, (c + \tfrac{2}{3}\, c_1 + \tfrac{1}{3}\, c_2) = N, \text{ etc.}$$

$$(4)\qquad \left\{\begin{array}{l} (\tfrac{1}{2}\, (c + c_1) = N \text{ for plat A.} \\ (\tfrac{1}{2}\, (c + c_2) = N \text{ for plat B, etc.} \end{array}\right.$$

$$(5)\qquad \frac{p_1 c + p_2\, (\tfrac{2}{3}\, c_1 + \tfrac{1}{3}\, c_2)}{p_1 + p_2} = N. \qquad \begin{array}{l} (p_1 = 1) \\ (p_2 = 3) \end{array}$$

Another formula used by Kiesselbach (3), when every third plat was a check, was as follows:

$$C_1 = N. \text{ for A.}$$
$$C_2 = N. \text{ for B.}$$

These formulae are for the determination of normal yields without direct modification of the check. The writer has used two other methods which differ in that a modified value of the check plats is first determined, interpolation then being made between these to secure the normal yielding power of the intervening plats.

THE WEIGHTED CHECK METHOD

The first of these might be termed a weighted check method. In it, each check yield is multiplied by two or by three, then to this product is added the yield of the preceding and the following check, the average of these figures then being taken as the true check plat value and the usual interpolations made between these. The end checks require similar, but slightly different, treatment than the interior ones, since they have but one adjoining check. If the normal yielding power of the intervening plats were to be expressed in a formula so that it might be compared with the preceding formulae, it would be written about as follows:

$$\text{Normal yield plat A} = \tfrac{2}{3}\left(\frac{3c_1 + c_2}{4}\right) + \tfrac{1}{3}\left(\frac{c_1 + 3c_2 + c_3}{5}\right)$$

$$\text{Normal yield plat B} = \tfrac{1}{3}\left(\frac{3c_1 + c_2}{4}\right) + \tfrac{2}{3}\left(\frac{c_1 + 3c_2 + c_3}{5}\right)$$

$$C = \tfrac{2}{3}\left(\frac{c_1 + 3c_2 + c_3}{5}\right) + \tfrac{1}{3}\left(\frac{c_2 + 3c_3 + c_4}{5}\right), \text{ etc.}$$

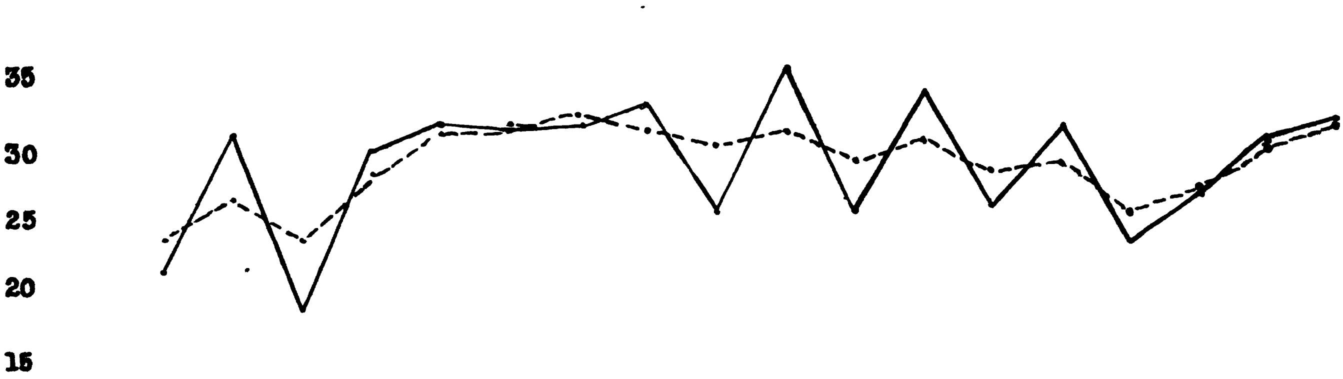

FIG. 1.—Showing "smoothing" effect of "weighted check" method of correcting check plat yields.

20.0 30.0 17.5 29.0 31.0 30.5 31.0 32.5 24.5 35.0 24.5 33.5 25.0 31.0 22.5 26.0 30.0 31.5
22.5 25.5 22.3 27.1 30.5 30.7 31.2 30.6 28.2 30.8 28.4 30.0 27.9 28.1 24.9 26.1 29.5 31.1

First line of figures and solid line graph = Actual Yields.

Lower line of figures and broken line graph $= \frac{3c_2+c_3+c_1}{5}$, etc.

Average yield = 28.05
Average yield (Mod.) = 28.07

Fig. 1 shows that this method is virtually a smoothing out of the yields as first obtained. In it each plat value is considered as paramount, but inexact, as large chance variation may and will very likely, occur, this variation being "smoothed" when weighted and averaged in this manner. This is similar to the weighting method of Stockberger, but differs in that average yields of all the checks are ignored. It corresponds to some degree with Richey's "moving average" method (4) of correction, but is limited to the correction of the checks from and by the check plat data.

THE "AVERAGE PERCENTAGE VALUE" METHOD

Wiancko (9) suggests that the value of the checks in permanent plat work be considered over a period of years rather than for one season, but no one seems to have expanded or adapted this idea. His suggestion is based on the discovery of a diminishing difference between non-treated checks as years of cropping passed by.

Harris and Scofield (1) have shown the interannual correlations of yields in such data as they found available in various journals and reports, including Stockberger's (8) data on hops and Smith's (7) data on corn. These correlations for the most part are of medium degree and significant in comparison with their probable errors. Negative correlation was found between low yields of corn in 1895 and higher yields in 1896 and 1897 in Smith's data on corn. The authors explain that in dry years lower parts of a field may excel in production and in a wet year the higher portions, giving a negative correlation between yields of the plats in successive years. They say that zero correlation may be found when "edaphic and meteorological factors exactly balance each other." From Stockberger's data on hops it is shown that correlations between first and fourth or first and fifth seasons are less than between first and second or first and third, or that there is some inclination toward variation with the lapse of time between the "relation" of yields of identical plats.

They then give correlations from 46 plats on the Huntley experiment farm in Montana from 1911 to 1919,—152 in all, of which 133 were positive and 19 negative. The average value of the positives was + 0.3346 and of the negatives — 0.1475. Of the 82 that are significant, 78 were positive and 4 negative.

These plats were 0.17 acre in size, approximately 1/6 acre. When in alfalfa, some records were obtained on successive cuttings and on alfalfa and corn some records of one-half (0.085 acre) and one-fourth plats (0.0425 acre) were taken. These approximate 1/12 and 1/24 acre plats. The coefficient of variation increased with the decrease in

Hay expressed in pounds; grain in bushels per acre.

Sec. No.	Plat No.	Cowpea hay, 1920	Corn, 1921	Oats, 1922	Wheat, 1923	Soy beans, 1924	Cowpea hay, 1920	Corn, 1921	Oats, 1922	Wheat, 1923	Soy beans, 1924	Average
							%	%	%	%	%	%
13	1	840	34.4	16.7	8.5	1,470	88.7	93.0	79.1	94.4	104.3	**91.9**
	4	750	37.0	18.3	7.8	930	79.2	100.1	86.7	86.7	66.0	**83.7**
	8	890	36.4	21.7	9.5	1,350	94.0	98.5	102.8	105.6	95.7	**99.3**
	12	1,110	38.8	26.2	11.3	1,520	117.2	104.4	124.2	125.6	107.8	**115.8**
	16	930	32.1	17.3	7.7	1,210	98.2	86.8	82.2	85.6	85.8	**87.7**
	20	1,160	43.0	26.1	9.2	2,000	122.4	116.3	123.7	102.2	141.8	**121.3**
		Oats	Clover	Corn	Oats	Wheat	Oats	Clover	Corn	Oats	Wheat	Average
14	1	12.2	3,620	49.0	23.8	14.5	77.2	101.7	108.4	94.1	96.0	**95.5**
	4	14.4	4,660	49.9	29.5	16.7	91.1	130.9	110.4	116.6	110.6	**111.9**
	8	19.7	3,900	48.9	33.8	18.8	124.7	109.6	108.2	133.6	124.5	**120.1**
	12	20.6	3,360	42.8	24.4	14.8	130.4	94.4	94.7	96.4	98.0	**102.8**
	16	13.8	2,630	39.7	18.9	11.1	87.3	73.9	87.8	74.7	73.5	**79.4**
	20	14.1	3,180	41.0	21.6	14.8	89.2	89.3	90.7	85.4	98.0	**90.5**
		Oats	Wheat	Clover	Corn	Oats	Oats	Wheat	Clover	Corn	Oats	Average
15	1	14.8	23.1	5,450	26.5	14.0	76.7	98.7	100.2	126.2	62.8	**92.9**
	4	18.0	23.3	6,820	26.4	22.2	93.3	99.6	125.4	125.7	99.6	**108.7**
	8	17.8	23.8	6,150	17.8	24.5	92.2	101.7	113.1	84.8	109.9	**100.3**
	12	23.9	23.8	5,210	20.1	26.1	123.8	101.7	95.8	95.7	117.0	**106.8**
	16	21.2	22.8	4,600	18.5	23.7	109.8	97.4	84.6	88.1	106.3	**97.2**
	20	20.0	23.8	4,400	16.7	23.0	103.6	101.7	80.9	79.5	103.1	**93.8**
		Corn	Oats	Wheat	Clover	Corn	Corn	Oats	Wheat	Clover	Corn	Average
16	1	36.2	18.1	12.2	3,980	57.0	93.5	66.3	76.7	100.3	93.6	**86.1**
	4	34.7	26.4	16.5	4,980	62.6	89.7	96.7	103.8	125.4	02.8	**103.7**
	8	40.0	27.3	17.1	4,670	64.7	103.4	100.0	107.5	117.6	106.2	**106.9**
	12	43.0	33.6	14.2	3,790	61.7	111.1	123.1	89.3	95.5	101.3	**104.1**
	16	39.2	31.1	18.0	3,930	60.3	101.3	113.9	113.2	99.0	199.	**105.3**
	20	39.1	27.3	17.3	2,440	58.8	101.0	100.0	108.8	61.5	96.6	**93.6**

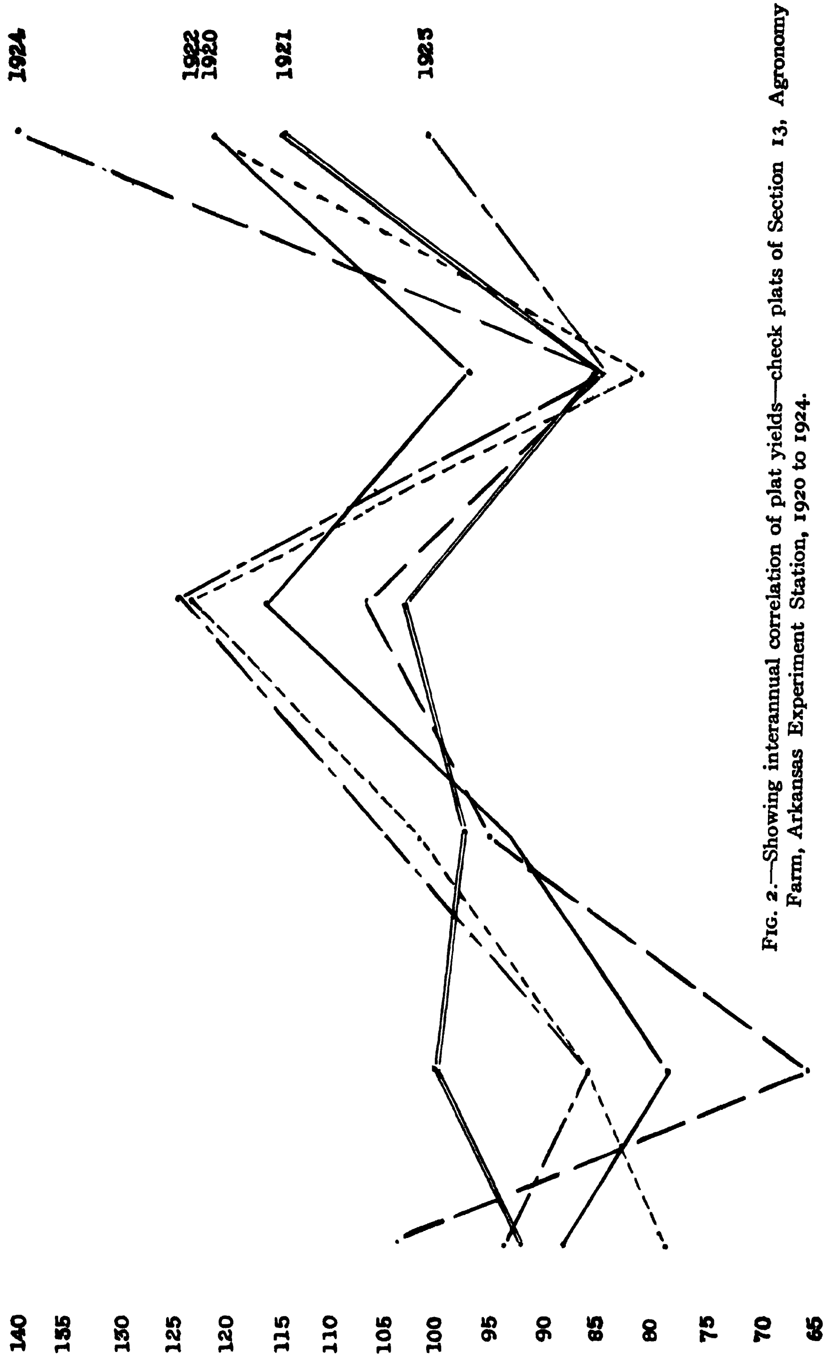

FIG. 2.—Showing interannual correlation of plat yields—check plats of Section 13, Agronomy Farm, Arkansas Experiment Station, 1920 to 1924.

size of plat and the coefficient of correlation decreased, the authors deducing that on such small areas other factors than individual plat peculiarities have too great an influence on yield to permit full expression of plat influence on successive yields.

Taking up Wiancko's idea and determining the value of a check plat for a series of years would necessitate getting some common factor which would apply to all the crops of a rotation. It seems as if the best way to accomplish this is to determine a "percentage value" of yield for each plat, not entirely dissimilar from that used by Stadler (6), but using a precentage obtained from the results of these plats in preceding years. Just how many years results one should use in determining this average value must be a conjecture; but in view of Wiancko's discovery of diminishing difference and Harris and Scofield's reduced correlation, it would seem advisable to use only a limited number of the most recent.

Table 1 shows the yield from several check plats (1/10 acre each) on fertilizer test plats of the Arkansas Experiment Station, this land having been first used for experimental work in 1920. The first column shows the yields of different crops in the rotation. In the other columns, but on the same line, will be found the percentage values of these check plats for the different years. The percentages are obtained by dividing the yield of a given check by the average of all the checks. This is done for each plat for each year. The true percentage value then of any one plat is the average of its percentages over the past four or five years.

Fig. 2 shows these percentages plotted, and indicates that the more fertile plats consistently give higher percentages, though there are one or two exceptions. The chance variation of any one year is then taken care of by averaging and the true value of a plat ascertained as near as is humanly possible. Thus, neither the high variation of plat 4 in 1921 (100.1%) nor the low variation in 1924 (66%) is used, as their use would give misleading and false conclusions. The average for the several years (83.7%) is more dependable. The work is completed by multiplying[4] the average yield of all the checks of a new crop by the percentage value of the respective check plats, including possibly the new yield for each of the check plats and thus deriving a new percentage value.

It would seem that by this method great confidence could be placed in the calculated yield of the check plats and that interpolation between these should rest on a very firm basis. There would be no serious detrimental effect of any very high or very low variation in yield in any one year.

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[4] However, the shortest method of adjusting would be to interpolate between these percentage values and divide each actual plat yield by its corresponding percentage value.

In rotations that have extended over a considerable period, it might be advisable to determine the percentage value for each crop. Thus for a corn crop, one could use a value determined from the last four or five corn yields and not from the last four or five years. This could be done also for oats and other crops.

Calculating the coefficients of correlation between these plats in different years, we find:

1920—1921	r = + .657	± .156	r/E_r = 4.21
22	+ .884	± .060	14.73
23	+ .715	± .135	5.30
24	+ .888	± .058	15.31
1921—1922	+ .852	± .075	11.36
23	+ .516	± .202	2.55
24	+ .738	± .125	5.90
1922—1923	+ .814	± .093	8.75
24	+ .768	± .113	6.80
1923—1924	+ .529	± .198	2.67

All of these correlations are of high degree and all but two of significance in comparison with their probable errors.

Both of the above-outlined methods have as their aim the correction of high or low variation in individual check plats and furnish a means whereby, without an undue amount of calculation, a reasonable valuation can be made of each plat of ground used as a check.

According to Richey (4), check plats should always be provided, but adjustment of yields would be warranted only when there is correlation of check plats to test plats. The Richey method of correction is elaborate and Hayes (2), though finding that adjustment to the regression on a moving average reduced the error 13 to 19%, questioned whether the reductions were "worth the trouble of making the calculations."

These methods assume and ignore the matter of correlation between test and check plats, which may not always be true. Applying these methods of correction of checks to the hop data for 1913, as given by Stockberger (8), it is found that they are little more accurate than the formulae which he used. Thus we find:

1. Using the "weighting methods"

(a) If a check yield be weighted by 2 and averaged with the ones adjacent, interpolation between these new check values will give an average deviation of 11.3% from the actual yields of the test plats.

(b) If 3 is used as the weight, the average deviation becomes 11.9%. Stockberger's formulae gave results varying from 8.3 to 13.3%.

2. Using the "average percentage value method."

(a) If the percentage be determined from the years 1909 to 1912, inclusive, the average deviation from actual yields becomes 13.1%.

(b) If the 1913 check yields be included in determining the value, the average deviation is 11.3%.

The coefficient of variability in Stockberger's data for 1913, if determined from all rows, is 19.1%, but if determined from the checks only becomes 24.9%, this higher variability in the checks making any method of correction appear of questionable value. Applied to 1914 yields, the "percentage value method" gives 12.73% (using a 5-year average) and 12.76% (using a 6-year average), where Stockberger has 15.1 to 19.4% deviation.

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GERMINATION OF RICE SEED AS AFFECTED BY TEMPERATURE, FUNGICIDES, AND AGE[1]

JENKIN W. JONES[2]

INTRODUCTION

The most troublesome weed pest in the California rice fields is water grass (*Echinochloa crus-galli*) and its varieties, which are widely distributed throughout the rice-growing area. These grasses grow well in water and their seed will germinate under water. However, while the rice seedlings stretch to the surface of the water, the grass seedlings are suffocated to a large extent. Taking advantage of this fact, rice growers are now using water to control or check the growth of water grass. The rice is sown broadcast from April 15 to May 20, and the fields are then continuously submerged with water until drained for harvest. At seeding time the temperature of the atmosphere, the soil, and the water used for irrigation usually is too low for maximum germination and rapid growth. Later in the season the temperature of the water and atmosphere may be too high for best results, and some growers have reported that the rice seedlings were "scalded" when germinated under shallow water.

In a study of the effects of temperature and moisture upon the germination of rice seed, Akemine (1, 2)[3] found (a) that the maximum, optimum, and minimum temperatures for the germination of rice are 104°, 86° to 95°, and 50° to 55.4° F.,[4] respectively; (b) that rice germinates equally well in water and in air, whether the grains are hulled or dehulled; (c) that the plumule appears sooner if the seed is placed in the air under favorable moisture conditions than if placed in water, and the radicle and crown roots also develop considerably sooner in the air than in water; (d) that after the plumule appears it grows much more rapidly in water than in air, the opposite being true of the radicle and crown roots; (e) that the frequent renewal of water had no sensible effect upon the development of the plumule, radicle, and roots, the same holding true for differences in

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[3] Reference by number is to "Literature Cited," p. 591.

[4] Data given by Akemine in degrees Centigrade, but for comparison with other data given in this paper they are converted to Fahrenheit.

depth of water, provided limits were between 1.2 to 8 inches; (f) that a suitable degree of moisture for the germination of rice is 60 to 95% by weight of the water-holding capacity of the seedbed; (g) that rice grains are saturated by a quantity of water equal to about 25 to 30% of their air-dry weight; and (h) that rice grains can not be made to germinate until they have absorbed a quantity of water equal to about 25% of their air-dry weight.

Da Fano (3), in experiments with five varieties of rice and three varieties of corn, made a study of the effect upon germination of varying the temperature, of the loss of moisture in the seed during exposure to the various temperatures, and of the percentage of moisture in the seed during germination. The experiment included the incubation of the seed of different varieties for from one to three hours at temperatures of 86°, 104,° 122,° 140°, 158°, 176°, and of 194°F[5]. This seed and the check then were germinated at a laboratory temperature of approximately 73.4°F. The author concludes that in rice the maximum germination was obtained after exposure of the seed for three hours at 86°F., except with the Ranghino variety, which attained its maximum germination after two hours' exposure at 104° F. The percentage of germination of the different varieties varied between 84 and 88%. The minimum germination obtained during three hours incubation at 176° F. varied from 18 to 24%, while incubation for one hour at 194° F. entirely destroyed the power of germination.

Harrington (4) found that rice germinated equally well at the following alternating temperatures:[6]

Approximate maximum temperature	85.1°F.	83.3°F.	91.4°F.	83.3°F.	90.5°F.
Approximate mean temperature	72.5°F.	72.5°F.	75.2°F.	74.3°F.	77.9°F.
Temperature at end of 15 hours	68.0°F.	70.7°F.	71.6°F.	72.1°F.	73.4°F.
Number of hours below 78.5°F.	16	14	12	11	10
Number of hours at 68°F.	12	4	3	3	2

Kondō (5) harvested rice at four stages of development: One, milk; two, yellow ripe; three, fully ripe; and four, dead ripe. When tested for germination, he found that the seed harvested in the milk stage was viable but lacked vigor, although he reports a satisfactory germination after drying. Storage for from one to three months improved the germination of the seed harvested in the yellow ripe stage. The ripe seed germinated well immediately after harvest but improved in viability with one month's storage. The dead ripe seed germinated very well soon after harvest and showed little improvement with storage. Drying in the sun improved the viability of immature grains, but storage in the panicles was found to be harmful. Seed harvested in the milk stage failed to develop plumules, while other seeds lacked the radicle at times.

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[5] Data given by Da Fano in degrees Centigrade, but for comparison with other data given in this paper they are converted to Fahrenheit.

[6] Data given by Harrington in degrees Centigrade, but for comparison with other data given in this paper they are converted to Fahrenheit.

Nagai (6) found that rice can be germinated at an extremely low oxygen pressure, but under such conditions the development of the radicle is totally inhibited. A supply of oxygen initiates the development of the radicle in seedlings thus germinated. No appreciable stimulation was observed in the germination of rice seeds as the result of variation of H and OH ions. The germination of rice was practically unaffected by a few hours' exposure to the extremely low temperature of liquid air; two hours' exposure of desiccated rice seed at temperatures of 206.6° to 208.4°F. only slightly affected its germination.

EXPERIMENTAL WORK

In California a considerable rice acreage is sown broadcast and immediately submerged. Information on the germination of rice under water and as affected by different temperature conditions is, therefore, of practical interest. Most of the experiments herein reported were conducted at the University of California in 1923 and 1924.

The purpose in conducting the experiments was to determine, if possible:

1. The effect on the germination of rice seed of long exposure under water to low temperatures compared with short exposure in a moist condition to high temperatures.
2. The effect on the germination of rice seed exposed in a dry condition for a short time to high temperatures.
3. The effect on germination of changeable temperatures compared with constant temperatures.
4. The effect of treatment with fungicides on rice seed germination.
5. The effect of age upon the viability of rice seed.
6. The effect of various seed defects on the germination of rice seed.

EQUIPMENT AND METHODS

In the experiment on exposure to low temperatures seed was placed in Petri dishes and submerged in water. The Petri dishes were then placed in refrigeration rooms which were maintained at practically constant temperatures. At the end of the period of exposure the water was changed on the seeds and they were placed under room temperature (60° to 80° F.) to germinate.

In the experiments on exposure to high temperatures and germination at constant temperatures, two electric ovens were used. One oven was constructed of zinc-lined wood and the other of asbestos with wire shelves. Each oven was equipped with a thermostat for temperature control. Standard Fahrenheit thermometers were used. It was not possible to adjust the thermostats to maintain a constant uniform tempertaure during the 24-hour day, and the oven temperatures varied from 2° to 4° F., when set for a given temperature.

The seed exposed in a moist condition was placed in Petri dishes, the bottoms of which had been covered with several layers of paper toweling. More than enough water was added to each Petri dish to saturate the paper. These containers were convenient, and excellent germination was obtained when the rice was placed on the saturated paper toweling and covered. The seed exposed in a dry condition was placed in clean dry Petri dishes.

Each sample consisted of either 50 or 100 seeds, and in several of the experiments duplicate samples were used. In some of the experiments the seed was germinated after exposure in a standard germinator with temperature control, while in others the germination was at room temperatures.

Eight varieties of rice were used in certain experiments; in others only one or two varieties were used. They included Caloro, Wataribune, Shinriki, Colusa, Eureka, Butte, Early Prolific, and Honduras. Colusa and Eureka are early maturing, Caloro and Butte are midseason, and Wataribune and Shinriki are late-maturing, short-grain rices. Early Prolific is a medium-grain variety, and Honduras a long-grain variety. Well-matured, recleaned seed from the Biggs Rice Field Station, of the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture, Biggs, Claif., was used in the experiments, the only exception being the Shinriki seed which was slightly immature.

EXPOSURE EXPERIMENTS WITH RICE SEED

I. EXPOSURE FOR A LONG PERIOD TO LOW TEMPERATURE

In these experiments the rice was placed in Petri dishes and submerged in water, or inclosed in saturated "rag dolls." The Petri dishes and "rag dolls" were then placed in refrigeration rooms at constant temperatures of 32°, 36°, and 40°F. The length of exposure

TABLE 1.—*Germination percentages of rice seed after exposure under water for 20 days at 36° and 40°F., and for 36 days at 32°, 36°, and 40°F., with notes on the character of resulting plantlets.*

Variety	Number of seeds	Germination percentages and growth									
		Exposed 20 days				Exposed 36 days					
		36°F.		40°F.		32°F.		36°F.		40°F.	
		Per cent	Character	Per cent	Character	Per cent	Character	Per cent	Character	Per cent	Character
Colusa	100	95	V.[b]	98	V.			77	V.	97	V.
Eureka	100	78	F.	96	V.V.			61	V.	81	V.
Caloro	100	25	W.	70	W.	15	W.	15	P.	53	P.
Butte	100	84	V.	85	V.V.			57	F.	57	P.
Wataribune	100	95	V.	99	V.V.			82	V.	94	V.
Shinriki	100	8	V.W.	23	V.W.			00	—	2	V.W.
Early Prolific	100	85	V.W.	98	F.			73	P.	98	F.V.
Honduras	100	8	V.W.	25	V.W.			5	V.P.	23	V.W.
Caloro—Control[a]	100	79	V.V.	92	V.V.	97	V.	97	V.V.	90	V.
Caloro in "rag doll"	100	57	V.V.	62	V.V.	8	W.	17	V.V.	45	V.V.

[a] Not exposed at low temperatures.

[b] Symbols in columns headed "Character" signify the following: V.V. = very vigorous; V. = vigorous; F.V. = fairly vigorous; F. = fair; P. = poor; W. = weak; and V.W. = very weak.

is indicated in Table 1. At the end of the period of exposure the samples were removed to a room in which the temperatures varied from 60° to 90° F. Fresh water was added to the Petri dishes and the "rag dolls" were again saturated with fresh water. All seed, except that in the "rag dolls," was germinated under water in the Petri dishes. The results obtained in these experiments are presented in Table 1.

During exposure at 32°F. the "rag doll" was frozen solid, but no ice formed in the Petri dish. While no actual weight tests were made, the rice seed did not appear to absorb water very readily at low temperatures.

After exposure at 36° F. for 20 days, the Colusa, Wataribune, Early Prolific, and Butte varieties showed a comparatively high percentage of germination, whereas the germination of the remaining varieties appeared to have been materially reduced. The percentage germination of all varieties was higher after exposure for 20 days at 40° than at 36° F., and the same varieties, Colusa, Wataribune, and Early Prolific, had a slightly higher percentage of germination than did the Caloro control. The average germination of the five control lots in these experiments was 91%.

The germinating power of Caloro seed was greatly reduced by exposure for 36 days at 32°F. The vitality of the seed was less affected under water than in a "rag doll."

The percentage germination of all varieties was higher after exposure at 36° and 40° F., respectively, for 20 days than for 36 days, except for Early Prolific, which had the same percentage germination in both tests. In three of the five experiments the percentage germination of Caloro seed after exposure was higher in Petri dishes than in "rag dolls," and in both containers the germination was decidedly lower after exposure than for the unexposed seed.

These results indicate that Colusa, Wataribune, and Early Prolific are more resistant to the detrimental effects of long exposure under water than are the other varieties used in these experiments. The poor germination of Shinriki no doubt was partly the result of using slightly immature seed. This indicates that well-matured rice seed is more resistant to adverse conditions than immature seed.

During the exposure period more or less fungous growth developed on the seeds, and this may have affected germination. However, in some instances the percentage of germination was high in spite of the considerable fungous contamination.

2. EXPOSURE FOR A SHORT TIME TO HIGH TEMPERATURES

In this experiment Caloro seed was placed in Petri dishes and submerged in water. Different samples were exposed daily for two, four, six, and eight hours, respectively, to a temperature which varied from 100° to 118°F., the average during the experiment being 110°F. When not exposed to heat the seed was kept at room temperature, 60° to 80° F. This test was started March 6 and continued until March 12. The results obtained are given in Table 2.

The percentage of germination was materially decreased by exposure for eight hours each 24-hour day, but exposure for two, four, and six hours each day appeared to stimulate and, possibly, slightly to increase germination.

TABLE 2.—*Effect on the germination of different lots of Caloro rice seed under water exposed each day until germinated to a high temperature for two, four, six, and eight hours, respectively.*

Lot number	Number of seeds	Number of hours exposed	Germination March 8 %	Germination March 12 %	Remarks
2	100	2	15	87	Vigorous seedlings
4	100	4	6	83	Vigorous seedlings
6	100	6	4	87	Vigorous seedlings
8	100	8	0	58	Fairly vigorous
1	100	0	0	82	Vigorous seedlings
7	100	0	0	83	Vigorous seedlings

3. EXPOSURE FOR ONE, TWO, AND THREE HOURS, RESPECTIVELY, TO HIGH TMEPERATURES

Duplicate samples of Colusa and Caloro rice seed were used in this experiment. The seed was placed on saturated paper toweling in Petri dishes and exposed for one, two, and three hours, respectively, to constant temperatures of 122°, 130°, and 152°F. An unexposed control and the exposed seed were germinated at a constant temperature of 86°F. The results obtained in this experiment are presented in Table 3.

TABLE 3.—*Effect on germination of exposing rice seed in a moist condition for a short time to high temperatures.*

Variety	Number of seeds	Percentage germination and temperature and length of exposure										
		122°F.		130°F.		152°F.			152°F.[a]			Control,
		1 hr.	2 hrs.	1 hr.	2 hrs.	1 hr.	2 hrs.	3 hrs.	1 hr.	2 hrs.	3 hrs.	not exposed
Colusa......	100	98	98	95	92	40	11	0	0	0	0	98
Colusa.......	100	98	—	93	97	79	0	0	0	0	0	100
Caloro.......	100	97	96	99	72	90	0	0	0	0	0	98
Caloro.......	100	99	—	95	87	88	4	0	0	0	0	98

[a] Exposed on two successive days.

The results show that exposure at 122° and 130° F. for one or two hours had no appreciable effect on germination. Exposure for two hours at 130°F. appears to have reduced the percentage germination of the Caloro seed. Exposure for one hour at 152°F. materially reduced the percentage germination of both varieties; two hours' exposure to 152°F. practically destroyed the power of germination of both varieties; and three hours' exposure entirely destroyed the power of germination of both varieties. Either one, two, or three hours' exposure to 152° F. on two successive days destroyed the germination power of all seed.

4. EXPOSURE IN A DRY CONDITION TO HIGH TEMPERATURES

In these experiments the seed was placed in clean, dry Petri dishes and exposed for one hour. The exposed seed and the controls were then placed in Petri dishes, in which were several layers of water-saturated paper toweling, and germinated at a constant temperature of about 86° F. The results of these experiments are presented in Table 4.

TABLE 4.—*Percentage of germination of air-dried rice seed after exposure for one hour to high temperatures.*

Variety	Number of seeds	Percentage of germination at									
		122° F.	130° F.	140° F.	150° F.	158° F.	170° F.	190° F.	205° F.	212° F.	Control
Colusa	100	98	98	100	98	89	94	68	0	0	99
Colusa	100	98	98	100	100	53[a]	97	27	0	0	98
Caloro	100	99	96	98	96	97	55[a]	4	0	0	99
Caloro	100	98	98	97	97	99	90	5	0	0	98

[a] Rice began to ferment—possibly reason for low value.

The results indicate that exposure for one hour at 122°, 130°, 140°, 150°, and 158° F. apparently did not reduce the germination of either variety. One hour's exposure at 170°F. appeared to reduce the germination of the Caloro variety. At 190° F. the percentage germination of both varieties was greatly reduced. The Caloro seed was injured to a greater extent than the Colusa seed. At 205° and 212°F. one hour of exposure killed all seed of both varieties.

These experiments, when compared with those in which the seed was exposed in a wet condition, show very clearly that air-dried rice seed will stand a much higher temperature than wet seed without affecting its germination.

GERMINATION AT VARYING TEMPERATURES

Seed of eight varieties of rice submerged in Petri dishes was placed on a window sill with a southern exposure. During the period of germination the maximum temperature varied from 58° to 117°F., and the minimum temperature from 42° to 50°F.

Seed of the same varieties submerged in Petri dishes was placed in a room which remained comparatively constant in temperature, varying only from 65° to 71° F. during the germination period. The results obtained in these tests are presented in Table 5. The percentage of germination of the different varieties on the window sill varied from 70% for Shinriki to 100% for Colusa and Eureka. At this range in temperature all the varieties, except Shinriki and Honduras, showed a high percentage of germination. At the lower temperature (56° to 71° F) the germination was satisfactory but not quite so high as that at the higher temperature. However, five of the eight varieties used showed a germination above 90%.

TABLE 5 —*Percentage of germination and vigor of seedlings of eight varieties of rice germinated under widely varying and under rather constant temperatures.*

Variety	Number of seeds	42° to 117°F. Germination[a] %	42° to 117°F. Seedling vigor	65° to 71°F. Germination[a] %	65° to 71°F. Seedling vigor
In Petri dishes					
Colusa	100	100	Vigorous	98	Vigorous
Eureka	100	100	Vigorous	98	Vigorous
Caloro	100	95	Vigorous	83	Poor
Butte	100	97	Fair	95	Vigorous
Wataribune	100	100	Very vigorous	100	Vigorous
Shinriki	100	70	Fair	80	Vigorous
Early Prolific	100	99	Fairly vigorous	98	Very vigorous
Honduras	100	75	Weak	68	Weak
In "rag doll"					
Caloro	100	88	Very weak	91	Very weak

[a]Average percentage of duplicate lots of 100 seeds.

Under like conditions some rice varieties germinate much more quickly than others Germination proceeds much more rapidly at high temperatures than at low temperatures.

These experiments indicate that rice may be expected to germinate well at a comparatively constant temperature, if above 65°F., or at a daily range in temperature which may vary from 42° to 117°F.

GERMINATION AT CONSTANT TEMPERATURES

The preceding data show that rice germinates very well at daily variations in temperature from 42° to 117°F., or from 65° to 71°F. during the period of germination. To determine its germination at constant temperatures rice seed was germinated on saturated paper toweling in Petri dishes at constant temperatures. The results of these experiments are presented in Table 6.

The data show that at a constant temperature of 61°, 68°, 86°, 88°, 93°, and 100°F. the germination for both rice varieties used was above 93% in all cases. At a constant temperature of 108°F. all Colusa seed was killed and only a few seeds of Caloro germinated. At a constant temperature of 122°F. the seed of both varieties was so injured by the heat that no germination was recorded.

TABLE 6.—*Percentage of germination of rice seed at constant temperatures.*

Variety	Number of seeds	Percentage of germination 61°F.	68°F.	86°F.	88°F.	93°F.	100°F.	108°F.	122°F.
Colusa	100	93	96	97	100	98	98	0	0
Colusa	100	94	96	95	97	99	100	0	0
Caloro	100	97	93	96	99	96	95	11	0
Caloro	100	95	94	98	97	96	97	4	0

These results indicate that rice does not require an alteration in temperature in order to germinate well, and that at the constant temperatures used the germination of both varieties was excellent. However, at a low temperature, that is, about 61°F., germination was rather slow. The germination period at 61°F. extended from March 25 to April 9, while at 93°F. the seed was practically all germinated in five days.

EFFECT OF TREATMENT WITH FUNGICIDES ON THE GERMINATION OF RICE SEED

I. FUNGICIDAL TREATMENT AND GERMINATION IN PETRI DISHES AND "RAG DOLLS"

In some of the preceding experiments, especially those in which the seeds were exposed to low temperatures or germinated at low temperatures, fungi often developed on the seeds before germination. In some cases it was thought that possibly the fungi reduced the percentage of germination. On the other hand, seed badly infected with fungi often germinated well. At the suggestion of Prof. W. W. Mackie, Cerealist of the California Experiment Station, some seed was treated with fungicides before being prepared for germination.

In the first experiment samples of seed were treated as follows: (a) Dusted with copper carbonate; (b) dusted with copper sulfate; (c) soaked for one hour in a 1 to 400 solution of uspulun; and (d) untreated. Each lot of seed was submerged in water in Petri dishes at the time the uspulun lot was set to soak, so that all lots received water at the same time.

In the second experiment duplicate lots of seed were treated as follows: (a) Dusted with copper carbonate; (b) soaked for one and one-half hours in a 1 to 40 solution of copper sulfate; (c) soaked for one and one-half hours in a 1 to 400 solution of uspulun; and (d) untreated. The seeds after treatment were germinated, one part of each lot under water in Petri dishes and a second part in moist "rag dolls."

The results of the seed treatment experiments are presented in Table 7. Treatment with copper sulfate dust was very injurious and reduced the percentage of germination. Treatment with either copper carbonate dust or uspulun appeared slightly to stimulate early germination in some cases, but the data are not consistent enough to prove general stimulation. In one series of the second experiment the germination of the rice seed in "rag dolls" apparently was decreased by treatment with either copper sulfate or uspulun. In the Petri dishes the percentage of germination was about the same for treated and untreated seed. In the second series of the second experiment there was little difference in the percentage of germination in Petri dishes and in "rag dolls" for either treated or untreated seed.

In these experiments on seed treatment it was observed that the seeds were practically free of fungi and early germination seemed to be stimulated in some cases.

TABLE 7.—*Effect of treatment with fungicides upon the germination of Caloro rice seed.*

	First experiment		Second experiment			
			Series 1		Series 2	
Seed treatment	Germination[a]	Length of seedling	Germination	Length of seedling	Germination	Character
In Petri dishes						
None	90	15	97	10–20	92	Vigorous
Copper carbonate dust	95	5	96	3–12	93	Vigorous
Copper sulfate solution	18[b]	1	98	3–12	94	Vigorous
Uspulun solution	91	5	98	10–20	95	Vigorous
In "rag dolls"						
None			97	1–10	96	Vigorous
Copper carbonate dust			99	1–12	96	Vigorous
Copper sulfate solution			88	1–7	91	Vigorous
Uspulun solution			89	1–7	98	Vigorous

[a] Each lot consisted of 100 seeds.

[b] Copper sulfate dust used.

2. SEED TREATMENT AND GERMINATION UNDER FIELD CONDITIONS

On May 6, 1923, three lots of Caloro rice seed were soaked for one to two hours as follows: (a) In water; (b) in a 1 to 40 solution of copper sulfate; and (c) in a 1 to 400 solution of uspulun. Part of the seed from the lot soaked in water was later thoroughly dusted with copper carbonate. After treatment six systematically replicated rod rows of each seed lot were sown in the nursery on well-prepared land.

The rows were spaced 3 feet apart and the seed spaced 3 inches apart in the rows, making 66 seeds sown in each row. All seed was carefully covered after hand sowing.

The land was irrigated and drained on May 7. After the first irrigation the land was irrigated and drained at intervals of about eight days until the rice emerged.

Careful observations were made during germination and emergence of the rice, but no stimulating effect was noted from seed treatment. In fact, the seed treated with copper carbonate was considerably slower in emerging than the untreated seed or the seed treated with copper sulfate or with uspulun. Examination of some of the seeds dusted with copper carbonate, which failed to emerge, showed that they had germinated but the seedling had failed to grow. This probably indicated that after germination the copper carbonate had a toxic effect on the seedlings.

The results secured in this experiment are presented in Table 8. The stands obtained in the replicated rows for the same treatment varied considerably. Thus, the number of seedlings that emerged, based on the number of seeds sown, for the untreated rows ranged from 27.3 to 48.5%, or a variation amounting to 43.7% of the maximum. The copper carbonate rows ranged in emergence from 34.9 to 53%, the copper sulfate rows from 50 to 68.2%, and the uspulun rows from 41 to 53%. While the results show that more plants emerged from treated seed than from untreated seed, it seems doubtful whether seed treatment actually increased the stand. The increase probably should not be attributed entirely to seed treatment, since other factors probably were involved.

TABLE 8.—*Effect of treatment with fungicides upon the field germination of Caloro rice seed.*

	Untreated		Copper carbonate		Copper sulfate		Uspulun	
Row No.	Number of seedlings emerged	Percentage of emergence	Number of seedlings emerged	Percentage of emergence	Number of seedlings emerged	Percentage of emergence	Number of seedlings emerged	Percentage of emergence
1	24	36.7	23	34.9	36	54.6	30	45.5
2	23	34.9	27	41.0	44	66.7	35	53.0
3	32	48.5	30	45.5	44	66.7	27	41.0
4	24	36.4	35	53.0	45	68.2	34	51.5
5	18	27.3	30	45.5	33	50.0	34	51.5
6	24	36.4	34	51.5	40	60.6	34	51.5
Total	145	—	179	—	242	—	194	—
Average percentage of emergence	36.7	—	45.2	—	61.1	—	49.0	

EFFECT OF AGE UPON THE VITALITY OF RICE SEED

I. EFFECT OF LONGEVITY UPON THE GERMINATION OF RICE SEED

There is little information regarding the effect of age on the germination of rice seed. This question is of interest to rice growers as well as to those engaged in experimentation and breeding. Crop failure, or loss of the crop as the result of unfavorable weather conditions, or fire, may make it necessary to use old seed in planting the next crop. Information regarding the germination of old seed. therefore, is of interest.

Eight varieties of rice, the seed of which varied in age from one to six years, were used in this test. The seeds, 100 in each lot, were germinated under water. During the germination period the average maximum temperature was 93.2°F., and the average minimum temperature 72.5°F. The results obtained in this experiment are presented in Table 9.

TABLE 9.—*Germination percentages of rice seed of eight varieties, ranging in age from one to six years.*

Seed		Germination percentages							
Year grown	Age in years	Colusa	Caloro	Wataribune	Fukuyama	Omachi	Butte	Carolina White	Honduras
1917	6	31	3	4	75	0	—	—	—
1918	5	85	45	41	86	5	—	—	—
1919	4	64	20	19	86	12	53	54	22
1920	3	85	19	24	98	72	98	96	99
1921	2	99	61	93	100	100	99	100	99
1922	1	100	99	99	100	99	98	98	99

The data indicate that some rice varieties deteriorate more rapidly with age than others. Seed of Fukuyama and Colusa four, five, and six years old germinated much better than did seed of Wataribune, Omachi, and Caloro. It appears probable that some factor other than age affected the germination of seed harvested in 1919. This seed may have been slightly immature. From the data it appears that rice seed stored in a dry condition should give a relatively high germination until three years old. Seed stored for a longer time is likely to be decidedly low in vitality.

2. EFFECT OF STAGE OF MATURITY ON THE GERMINATION OF RICE SEED

In September and October, 1923, seed of three varieties of rice was harvested at five different stages of development; the milk, dough, hard dough, first ripe, and dead ripe. When harvested the panicles were placed in manila paper bags and kept in a dry condition until used for germination tests in January, 1924. Triplicate lots of 50 seeds each for all stages of development were germinated between moist sheets of blotting paper at a constant temperature of 82°F. The lots were germinated at the same time in one large container so that all samples were germinated under like conditions of temperature, moisture, etc. The period of germination was from January 29 to February 9. The results obtained are presented in Table 10.

TABLE 10.—*Effect of stage of maturity on the germination of rice seed.*

	Percentage of germination						
	Individual lots			Average			Average for the three varieties
Stage of maturity	Colusa	Wataribune	Early Prolific	Colusa	Wataribune	Early Prolific	
Milk stage	0	10	4				
Milk stage	0	16	6				
Milk stage	0	18	8	0	15	6	7
Dough stage	36	82	60				
Dough stage	48	66	86				
Dough stage	70	28	80	51	59	75	62
Hard dough stage	74	64	50				
Hard dough stage	80	66	70				
Hard dough stage	76	70	64	77	67	61	68
First ripe	90	86	98				
First ripe	88	96	98				
First ripe	92	90	98	90	91	98	93
Dead ripe	96	100	100				
Dead ripe	98	96	98				
Dead ripe	98	100	98	97	99	99	98
Field threshed	100	98	100				
Field threshed	96	96	98				
Field threshed	98	100	98	98	98	99	98

There was no germination of the Colusa seed harvested in the milk stage. The Wataribune and Early Prolific seed harvested at this stage germinated, although very poorly. There was a marked increase in germination in all varieties with each successive stage of development from the milk to the dead ripe stages. A minor variation from this tendency occurred with Early Prolific, which gave about the same germination for the seed harvested in the first ripe and dead ripe stages. Field-threshed seed and dead ripe seed germinated about the same.

The results show that the ability of rice seed to germinate increases with each successive stage of maturity.

GERMINATION OF NORMAL AND DEFECTIVE RICE SEED

The use of rice seed which is not well matured, or which contains brown-hulled kernels, dehulled kernels, dehulled half-kernels, etc., is not recommended but may be necessary in certain cases. The value of such seed when sown is, therefore, of practical interest. Caloro rice seed of each of these defective groups was prepared in 100-seed lots and was germinated between sheets of moist blotting paper. The temperature during the period of germination varied from 55° to 102°F., the greatest daily range being 41°F. The results of this experiment are presented in Table 11.

TABLE 11.—*Percentages of germination of well-matured, immature, brown-hulled, and dehulled kernels, and hulled and dehulled half-kernels of rice.*

Variety	Number of seeds	Condition of seed	Germination %
Caloro	100	Well matured	96
Caloro	100	Immature	67
Caloro	100	Brown-hulled	92
Caloro	100	Dehulled	86
Caloro	100	Hulled half-kernel	95
Caloro	100	Dehulled half-kernel	100

The germination for the different lots varied from 67% for the immature seed to 100% for the dehulled half-kernels containing germs. The temperature apparently was ideal for germination in this test. Under field conditions at the usual date and rate of seeding the percentage germination for all lots probably would have been much lower than those here reported. The results show, however, that under favorable conditions brown-hulled and dehulled kernels, and hulled and dehulled half-kernels containing germs can be used for seed, if necessary.

SUMMARY

The results of these experiments indicate:

1. Seeds of some rice varieties are more resistant to deterioration during long exposure under water at low temperatures than those of other varieties. Colusa, Wataribune, and Early Prolific appear to be the most resistant of the varieties used in these experiments.

2. An exposure of eight hours under water at 100° to 118°F. in each 24-hour day greatly reduced the germination of Caloro seed, while two, four, and six hours' exposure each day did not noticeably affect germination.

3. The exposure of moist rice seed for one and two hours at 122° and 130°F. had no appreciable effect on germination. An exposure for one hour at 152°F. materially reduced the germination of seed of both the Caloro and Colusa varieties. A two-hour exposure practically killed all seed of both varieties, and a three-hour exposure entirely killed all seed of both varieties.

4. An exposure of dry rice seed for one hour at 122°, 130°, 140°,

150°, and 158°F. did not affect germination. A one-hour exposure at 170°F., appeared to reduce the germination of Caloro seed. A one-hour exposure at 190°F. greatly reduced the germination of both Caloro and Colusa rice, and at 205°F. all seed was killed.

5. Rice seed germinated very well when subjected to a range in temperature from 42° to 117°F., or from 65° to 71°F. during the period of germination. Some varieties germinate more quickly than others and all varieties germinate quicker at high than at low temperatures.

6. Rice seed germinated about equally well at constant temperatures of about 61°, 68°, 86°, 88°, 93°, and 100°F. At 108°F. no seeds of Colusa, and only a few seeds of the Caloro variety, germinated. At 122°F. all seeds of both varieties were killed.

7. Seed treatment with copper carbonate dust, a 1 to 40 solution of copper sulfate, or a 1 to 400 solution of uspulun prevented the growth of fungi, and in some cases appeared to stimulate the germination of rice seed submerged in Petri dishes.

8. Seed treatment with the above fungicides resulted in better stands under field conditions, but the increased stand may have resulted from other factors than seed treatment. Copper carbonate appeared to be toxic to some seedlings after germination.

9. The seeds of some rice varieties appear to deteriorate with age faster than others. Three-year-old seed of five varieties tested ranged in germination from 85 to 99%, while the other three varieties in the test ranged in germination from 19 to 72%. The vitality of rice seed more than three years old is likely to be low.

10. The percentage of germination of rice seed, harvested at different stages of development, increased with increased maturity from the milk to the dead ripe stages.

11. Brown-hulled and dehulled kernels and dehulled and hulled half-kernels of rice germinate well under favorable conditions. Immature seed usually is low in vitality.

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RELATION OF BREAKING STRENGTH AND OTHER COB CHARACTERS TO YIELD OF CORN[1]

F. L. WINTER[2]

During 1920, a farmer and seed grower near Pekin, Illinois, divided his corn for planting into two lots on the basis of the breaking strength of the cobs. The corn from cobs having a breaking strength of 60 pounds or more was planted in one plat and the corn from cobs having a breaking strength of less than 30 pounds was planted in another plat. The yields secured from these plats indicated that the corn from the cobs with the higher breaking strength yielded better than the corn from the cobs with the lower breaking strength.

The writer is not aware of any other work pertaining to the relation of breaking strength of cob to yield of the succeeding crop. Other cob characters, however, have been found to be correlated with yield per cob. Grantham (1)[3] states that "the yield of grain per ear is strongly correlated with the circumference of the cob" and that "the yield of grain per ear is correlated to a considerable extent with the weight of cob." Hutcheson and Wolfe (2) state that the relation between yield and the average circumference of cob of the same crop is significant. Their data are based on the average circumference of all the cobs from a high-yielding strain taken as a unit compared with the average circumference of all cobs from a low-yielding strain taken as a unit.

As a result of this work, an experiment was conducted by the writer at Urbana, Illinois, to determine the relationship between cob breaking strength and the yield of corn. Five different strains of corn were used in this experiment, *viz.*, Illinois Special High Yield, Illinois High Yield, Illinois Low Yield, Illinois Non-Pedigree, and Woodford County. The history of the first four strains is given by Smith and Brunson (4). The Woodford County strain is a yellow dent strain composited from four of the ten highest yielding strains of corn as determined by a three-year trial test in Woodford County,

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[2] First assistant in Plant Breeding.

[3] Reference by number is to "Literature Cited," p. 596.

Illinois. The yields reported in this paper were obtained from five-row test plats replicated four times, planted to a composite of seed of each strain, coming from cobs that were tested for breaking strength. The yields were calculated on a 12% moisture basis.

The average breaking strength, the average diameter, and the average stress value[4] of the cobs of the seed ears of these five different strains of corn were determined in the fall of 1922. The air-dry cobs were broken by means of a self-recording, motor-driven tension machine, such as is ordinarily used in testing the tensile strength of wire and allied material. The cobs were broken crosswise with a horizontal pull directed at the center of a 4-inch section, equidistant from the butt and the tip of the cob. In Table 1 are given the average values of the above-mentioned cob characters and the yields in bushels per acre of the resulting crop (1922).

TABLE 1.—*Average breaking strength, average diameter, and average stress value of the cobs of seed ears of each strain of corn, together with the yields of the resulting crop (1922).*

Strain	Average breaking strength of cob in pounds	Average diameter of cob in cm.	Average stress value of cob	Average yield in bushels per acre
Illinois Special High Yield	120.45±2.28	3.05±0.013	4.65±0.075	73.4±0.47
Illinois High Yield	105.36±2.06	2.85±0.020	5.13±0.116	70.2±0.24
Illinois Non-Pedigree	96.00±1.81	2.87±0.019	4.42±0.021	72.5±0.55
Woodford County	86.93±1.34	2.75±0.010	4.64±0.058	67.1±2.45
Illinois Low Yield	80.88±2.73	2.89±0.014	3.69±0.086	53.7±0.55

TABLE 2.—*Coefficients of correlation between the average breaking strength, the average diameter, and the average stress value of the cobs of seed ears, and the yield of the resulting crop.*

	Average diameter of cob in cm.	Average stress value of cob	Average yield in bushels per acre
Average breaking strength of cob.....	0.73±0.14	0.62±0.18	0.77±0.12
Average diameter of cob.............		0.08±0.30	0.23±0.29
Average stress value of cob.....			0.08±0.30

In Table 2 are given the coefficients of correlation, calculated by the Phillips (3) method, between the average breaking strengths, the average diameters, and the average stress values of the cobs of seed ears, and the yields of the resulting crop.

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[4] The term stress value (s. v.) as here used denotes the relative strength per unit area of the ligneous part of the cob. This value was secured by dividing the breaking strength of the cob (s) by the difference between the diameter of the cob (d_1) cubed and the diameter of the pith (d_2) cubed. $\text{s. v.} = \frac{s}{d_1^3 - d_2^3}$.

The data in Table 2 show a high positive correlation ($r = 0.77 \pm 0.12$) between the average breaking strength of seed-ear cobs and the yield of the resulting crop. There is also a high correlation ($r = 0.73 \pm 0.14$) between the average breaking strength of cob and the average diameter of cob. However, the correlation between the average diameter of cob and the average yield ($r = 0.23 \pm 0.29$) is not significant. The correlation ($r = 0.62 \pm 0.18$) between the average breaking strength and the average stress value indicates that there is an actual increase in strength per unit area of the cob as the diameter increases. However, this is not a perfect relationship. The data in Table 1 indicate that the differences in the average stress value for the different strains are not as significant as are the differences in average breaking strength or in average diameter of cobs. The average stress value is not significantly correlated with either the average diameter or the average yield of corn.

The color of the ligneous part of the cobs at the point of break was noted. Four classes of colors were made, *viz.*, pink, red, brown, and black. The percentages of the different colors for the five strains, together with the yields of the resulting crop, are given in Table 3.

TABLE 3.—*Classification of the seed ear cobs of the five different strains in percentage, according to the color of their ligneous parts, together with the yield of the resulting crop.*

Strain	Color of ligneous part of cob				Average yield in bushels per acre
	Pink	Red	Brown	Black	
Illinois Special High Yield..	23.6	35.4	39.6	1.3	73.0
Illinois Non-Pedigree......	17.1	19.4	63.5		72.5
Illinois High Yield........	11.0	26.0	63.0		70.2
Woodford County........	12.2	32.0	55.8		67.1
Illinois Low Yield.......	7.0	15.8	77.2		53.7

It appears in general that the higher yielding strains have a higher percentage of seed-ear cobs with pink and red ligneous parts and a lower percentage of brown ligneous part than the lower yielding strains. The Woodford County strain is a noticeable exception to this. When the correlation coefficients were calculated, a high positive correlation ($r = 0.79 \pm 0.11$) was found to exist between the pink coloration of the ligneous part of the cob of seed ears and the yield of the resulting crop. There is also a positive correlation ($r = 0.60 \pm 0.19$) between red color and yield. There is a significant negative correlation ($r = -0.74 \pm 0.14$) between brown coloration of the ligneous part of the cob and yield.

Though no critical study was made of these colors, they have been considered to be inherent characters and not due to pathological conditions. This is particularly true of the pink and red colors. In the case of the brown color, however, the only indication that the cause might be pathological is the negative relationship which this color bears to yield. Brown cob color, therefore, has been considered in this paper as an inherited character. The writer does not feel justified in drawing any conclusions concerning the cause of the black cob color because only two such cobs were found and these occurred in only one strain.

In 1922 the average breaking strength and the average diameter of 100 cobs upon which first year self-fertilized seed was borne were found to be 89.5 ± 3.12 pounds, and 2.71 ± .019 centimeters, respectively. In 1923 the average breaking strength and the average diameter of 80 cobs borne on stalks coming from first year self-fertilized seed (selfed in 1922) were 65.9 ± 3.45 pounds, and 2.56 ± .014, respectively. The results illustrate further the well-known deleterious effects accompanying inbreeding.

In the fall of 1923 breaking strength and diameter of seed ear cobs were obtained on only the Illinois Special High Yield and Illinois Non-Pedigree strains to compare with their yields for the year 1923. This comparison is shown in Table 4.

TABLE 4.—*The average breaking strength and average diameter of seed-ear cobs for each strain, together with yields for 1923.*

Strain	Average breaking strength of cobs in pounds	Average cob diameter in cm.	Average yield in bushels per acre
Illinois Non-Pedigree	81.8±1.87	2.84±0.007	71.8±1.16
Illinois Special High Yield	75.2±1.18	2.81±0.015	67.2±0.94

The data in Table 4 indicate a positive relationship between the average breaking strength of seed-ear cobs and yield of corn. It is interesting to note that the two strains gave results that were the reverse of those secured in 1922; also, that both the yields and the breaking strength for these strains were lower in 1923 than in 1922. The average diameter of cob is also positively related to yield, but the difference between the two strains is not significant.

It appears from the above data (a) that each of the strains has a distinct average cob breaking strength, (b) that there is a positive relationship between this breaking strength and yield when strains are compared, (c) that there is a positive correlation between either pink or red coloration of the ligneous part of seed-ear cobs and average yield, and (d) that a negative correlation exists between brown coloration of the ligneous part of seed-ear cobs and average yield.

Such relationships may have a limited value in securing seed for planting. If all seed ears are shelled individually by hand one can readily observe the cob color by breaking the cob after shelling. The color, together with the relative ease or difficulty with which the cob breaks, is a further aid in deciding whether a given ear shall be used for seed.

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ARTIFICIAL PLATS FOR FIELD EXPERIMENTS[1]

T. L. Lyon and E. W. Leland[2]

In an endeavor to avoid the variations in soil productivity which always occur in field areas, there was adopted at the Cornell Experiment Station, some years ago, the use of what might be termed artificial plats. A number of these have now been in use for seven years and have been found to possess some decided advantages over field plats. The artificial plats are bounded by concrete walls which constitute the four sides. On account of this construction they are usually called "frames." Since the constructed part consists only of walls, the bottom or floor is formed by the subsoil, the top soil having been removed before the walls were built. The main feature of the artificial plats which makes it possible to secure greater accuracy than with natural ones is that they are filled with soil made uniform by mixing. Only the subsoil is a variable constituent of the medium in which the plant grows. The depth of the soil layer introduced may be varied according to the needs of the experiment.

The first step in building the artificial plats is to remove that portion of the soil corresponding to the plow depth. This is placed in a pile and may or may not be used for filling the frames depending on the nature of the experiment to be conducted. In order to have the walls deep enough to prevent plant roots from spreading from one

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[2] Professor and Experimentalist in Soil Technology, respectively.

frame into the fertilized soil of another the excavations are sunk 10 inches into the subsoil. The walls are then built to a height of 20 inches which allows for a rim of 2 inches above the soil when the frame is filled with 8 inches of surface soil.

The walls are 6 inches in thickness. Two inches below the top of the wall is at least one opening, about an inch in diameter, through which water may escape when it would otherwise stand on the surface of the soil. Tile drains are laid outside and slightly below one wall of each frame.

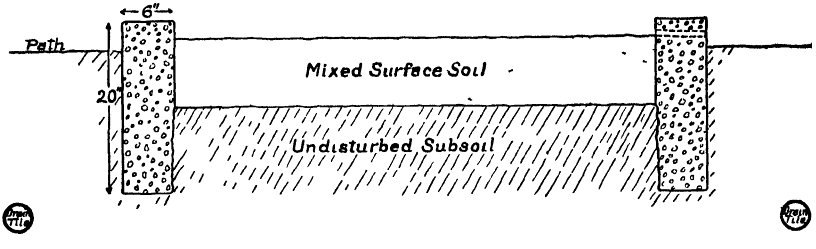

FIG. 1.—Cross section of concrete frame.

When the frames are to be filled with soil the main consideration is to mix it as thoroughly as possible, for the whole object of the rather expensive equipment is to obtain a uniform medium for plant growth. To accomplish this the soil is mixed in piles large enough to furnish one wheelbarrow load for each one of a series of frames. It would seem to be good practice to fill at one time as many frames as are to be used in one experiment or, in other words, to fill all the frames between which comparisons are to be made. A new pile is then mixed and another wheelbarrow load is placed in each frame. This is continued until the frames are full, the soil within each frame meanwhile being mixed as the frame is being filled. It has been found desirable to weigh each wheelbarrowful of soil in order to have an equal quantity of surface soil in all frames. If the soil used is brought from a distance the same method of filling is followed. Some frames have been filled with 8 inches of surface soil and 8 inches of subsurface soil. In such cases the walls are made 24 inches high.

A feature of the building operations not previously mentioned is that of grading for the foundation of each frame. When the first set of frames was built this was not done and consequently the tops of the walls followed the natural contours of the land. This is evident in those frames on the right of the picture in Fig. 2. It was objectionable because the surface of the soil within the frames was not everywhere equally distant from the top of the partition or, if it was, the surface of the soil was not level. Frames built later had the subsoil leveled for each frame and the tops of the partitions for any frame are on the same level. If there is a rise of ground one frame is set at a higher elevation than another forming steps as they ascend the grade. This is well shown in Fig. 4, and also on the left in Fig. 2.

The first frames made were 4 feet, 8 inches square, giving an area of 0.0005 of an acre. These were rather too small for corn planted for grain production and an area twice as large was enclosed in frames built later. The dimensions of the latter were 4 feet, 8 inches by 9 feet, 4 inches. The frames built most recently enclose only 0.0001 of an acre. They are filled with soil brought from a considerable distance and on account of the expense involved in transporting the soil they were made as small as was thought consistent with accuracy in determining yields.

For the purpose of making a rather careful test of the experimental error that might be looked for in these smallest frames, 56 of them were subjected to the same treatment for three years and the crops, consisting of fodder corn in 1923, barley in 1924, and millet in 1925, were harvested. There were four types of soil, each type filling 14 frames. When the crops were removed they were dried in a room maintained at a temperature of about 150° F., and then weighed.

TABLE 1.—*Total yields in grams of three crops on frames of 0.0001 acre area.*

Ontario loam		Volusia silt loam		Wooster silt loam		Canfield silt loam	
No. of frame	Yield in 3 years	No. of frame	Yield in 3 years	No. of frame	Yield in 3 years	No. of frame	Yield in 3 years
1	1,402	29	1,094	57	1,228	85	1,101
2	1,348	30	1,042	58	1,173	86	1,201
3	1,192	31	1,197	59	1,184	87	1,092
4	1,375	32	1,147	60	1,182	88	1,139
5	1,340	33	1,154	61	1,056	89	1,203
6	1,402	34	1,078	62	1,174	90	1,196
7	1,363	35	1,122	63	1,119	91	1,216
8	1,352	36	1,113	64	1,199	92	1,100
9	1,253	37	1,119	65	982	93	1,064
10	1,273	38	1,088	66	1,023	94	1,113
11	1,317	39	1,148	67	1,095	95	1,092
12	1,302	40	1,105	68	1,180	96	1,104
13	1,187	41	996	69	1,134	97	1,111
14	1,199	42	1,017	70	1,199	98	1,188

In calculating the experimental error each soil type must, of course, be considered separately. The total yields of the three crops grown on each frame are stated in Table 1. These figures are included because they constitute the material on which the calculations

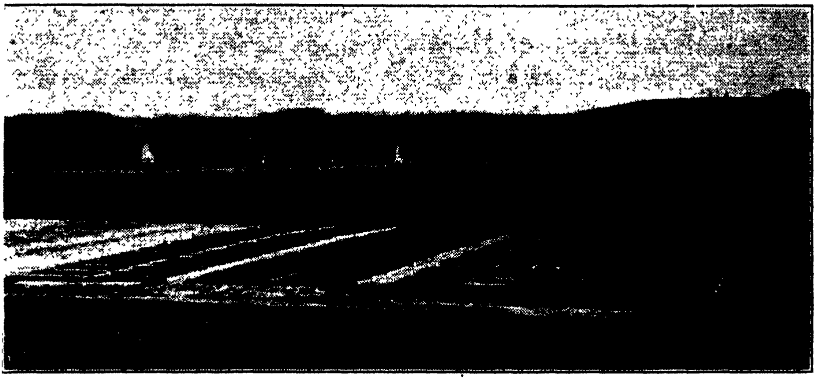

FIG. 2.—General view of frames. Those on the right of the picture are each 0.0005 acre in area; those on the left are each 0.001 acre.

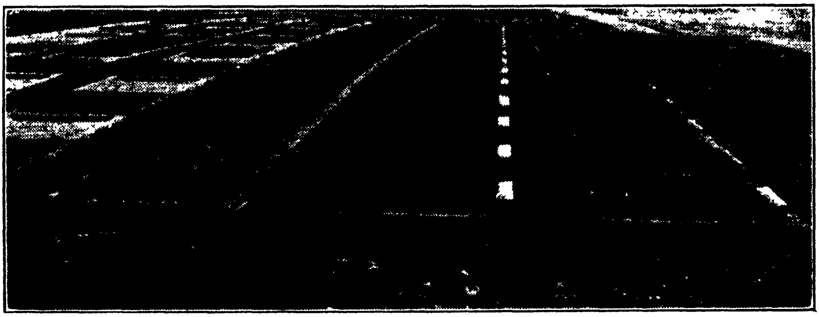

FIG. 3.—First frames built. The tops of the walls follow the contours of the ground.

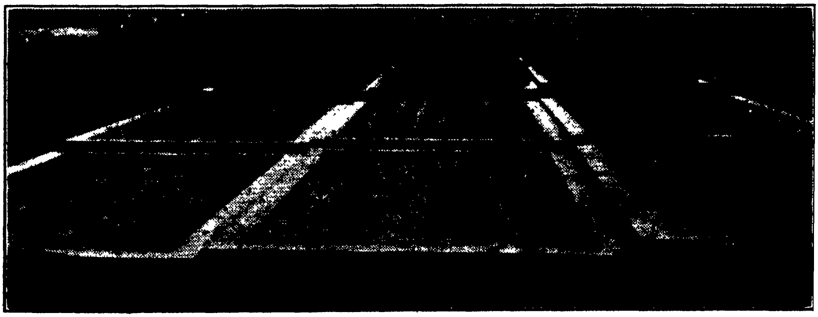

FIG. 4.—Frames built later. The surface of each frame is horizontal and they rise by steps to meet the contours of the ground.

of probable error are based. Bessel's formula has been used for making the computations of the probable error for any single frame of each of the 14 frames containing soil of the same type. The figures for these will be found in Table 2.

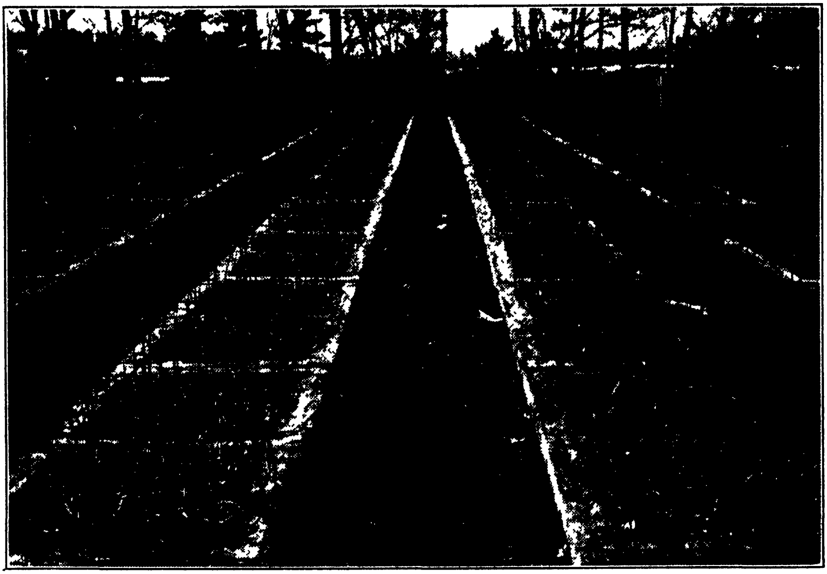

FIG. 5.—Frames of 0.0001 acre area with wire supports for plants.

The same table contains a column giving the probable error for the yields from any pair of duplicate frames. Since seven different treatments are to be given to each type, each treatment will be applied to two frames. It is possible, therefore, to use the combined yields of two selected frames, making seven observations, as the material for calculating probable error. This has been done by combining the yields of frames 1 and 8, 2 and 9, 3 and 10, etc., a similar procedure being followed for each soil type.

TABLE 2.—*Probable error expressed in percentage of mean yield on frames of 0.0001 acre area.*

Soil type	Any one of 14 frames	Any pair of duplicate frames
Ontario loam	±3.89	±2.41
Volusia silt loam	±3.38	±2.52
Wooster silt loam	±4.36	±2.61
Canfield silt loam	±3.09	±2.14

The experimental error for any pair of duplicate frames, as indicated by these calculations, is not excessive and will compare very favorably with large field plats. The smallest frames have been used for this test because one is apt to think that the smaller the plat the greater the experimental error is likely to be. However, this is not necessarily true of artificial plats containing uniform soil, if the number of plants grown is large enough to eliminate errors due to variations in the growth of individuals, and if mechanical difficulties are overcome.

With all of these frames it is desirable, and is possible, to give a degree of attention to the growing plants that is not usually accorded to the crops on ordinary field plats. For instance, lodging of cereals is prevented by the use of supports, wheat is protected from birds by wire netting, rainwater from a cistern is applied when moisture is deficient, plants may be sprayed if necessary, weeds are kept down, and an essentially pure culture of any desired plant may be maintained. This last point is of great importance in any experiment which involves the production of grasses free from clovers, especially alsike and white clover, both of which in this region are likely to appear most unexpectedly and unaccountably.

The artificial plats probably have their greatest usefulness when used for what is usually termed soil fertility experiments. The homogeneity of the soil makes sampling a much less speculative operation than on field plats the soil of which varies from point to point. The raised partitions between plats prevent the washing of fertilizers and help to prevent their being carried to other plats by the wind when used for topdressing, while the level surface of the soil obviates washing of either soil or fertilizer from one part of the plat to another. Another advantage is to be found in the small quantity of the harvested crop which makes it possible to dry it before weighing and obviates any need for sampling—an important precaution in some experiments.

Of course there are some types of field experiments for which the frames are not suited or for which they are needlessly expensive. Most variety tests would fall within this category, although for tests of grasses the frames are excellent since the partitions prevent grass from spreading into other plats.

Somewhat similar receptacles have been used at the Darmstadt Experiment Station for many years. They are 1 meter square and 1 meter deep. They are regarded by those who use them as providing a very accurate method of conducting field tests. They differ materially from our larger frames in that they are designed to furnish a substratum for the entire root system of the plants grown on them.

This greatly increases the cost of constructing and also of filling them.

If receptacles of this kind are to find an extensive use as a substitute for ordinary field plats, it is desirable that the cost of constructing and filling shall be reduced to the lowest figure consistent with reasonable accuracy. If corn or other intertilled crops are to be grown the area of the frames cannot well be less than the largest that we have described. For most cereals, grasses, clovers, and other closely planted crops there is probably little to gain in making the area greater than 0.0001 acre.

It is possible that some material for making the walls will be found that will be better or cheaper than concrete. The forms required for building concrete walls make their construction tedious and slow. However, concrete has the advantage of permanancy. We have adopted the practice of covering the concrete with asphaltum paint. If it were desired to prevent any calcium from reaching the soil it would be advisable to use a form of asphalt more durable than is the paint.

The practice of using only 8 inches of mixed surface soil is still something of an experiment, one of the unsolved problems being the influence which the subsoil may have in determining the experimental error. It is inevitable that plant roots will penetrate the undisturbed subsoil and its lack of uniformity may be expected to affect the uniformity of the crop yields. On heavy soils east of the Mississippi water shed this source of error is probably much less than it would be on the more porous and fertile subsoils farther west.

There are now somewhat more than 200 "frames" in use at the Cornell Experiment Station, and although they are doubtless still open to some objections, on the whole, they have been much more satisfactory than the ordinary field plats. While their construction was rather expensive, it has been a good investment.

EFFECT OF IMMATURITY ON SHRINKAGE, SHELLING PERCENTAGE, AND GERMINATION OF SEED CORN[1]

H. W. Alberts[2]

Where the corn crop is used for silage in the northern part of the corn belt, it is often necessary to harvest seed corn before the kernels are fully developed. If the plants are allowed to mature, the stalks and leaves become too dry for good silage. In some years the crop is attacked by frost before the end of the growing period. In either instance, the ears of corn which are to be used for seed are harvested before they are fully mature.

Under such conditions the moisture content is high and the development of the kernels is not completed so that their value for seed may be impaired. A study was made to determine the effect of harvesting corn at different stages of maturity on shrinkage, shelling percentage, and germination.

MATERIALS AND METHODS

Two varieties of corn were used: Golden Glow in 1919 and Murdock in 1920. The dates for harvesting Murdock corn were over two weeks later than the dates for the corresponding stages of Golden Glow. This difference was due partly to varietal characteristics, and also may have been due partly to seasonal differences because the tests were made in different years. Corn was harvested at intervals beginning with the milk stage and the last ears were harvested after the kernels were fully dented. Since there was a wide variation in the stage of maturity of plants in the field at a given time, only those ears which were developed farthest in a given area were selected. The husks were removed soon after the ears had been harvested. The ears were then weighed and dried in a well-ventilated room.

EFFECT OF IMMATURITY ON SHRINKAGE

Reduction in weight was determined by taking the difference between the weight of ears at the time of harvesting and the beginning of the germination test. The percentage of shrinkage was calculated, using the weight of ears at the time of harvesting as a basis. In the early milk stage moisture comprised over four-fifths of the weight of the ears and consequently the shrinkage was high. Shrinkage was lowest in corn that was harvested after it was fully dented. Shrinkage at this stage was 36% for Golden Glow and 50% for Murdock, as shown in Table 1.

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[1] Contribution from the Department of Agronomy, University of Wisconsin. Published with the approval of the director of the Wisconsin Agricultural Experiment Station. Received for publication April 26, 1926.

[2] Formerly Instructor in Agronomy.

TABLE 1.—*Showing shrinkage, shelling percentage, and germination of corn harvested at different stages of maturity.*

	Date harvested		Shrinkage		Shelling		Germination	
Stage of maturity	Golden Glow, 1919	Murdock, 1920	Golden Glow, 1919 %	Murdock, 1920 %	Golden glow, 1919 %	Murdock, 1920 %	Golden Glow, Feb. 1920 %	Murdock, Feb. 1921 %
Early milk stage	July 30	Aug. 14	84	79	25	45	14	75
Late milk stage	Aug 13	Aug. 30	73	70	70	72	74	87
Dough stage	Aug. 20	Sept. 6	54	67	75	75	99	97
Beginning glaze stage	Aug. 27	Sept. 13	44	58	82	85	99	98
Full dent stage	Sept. 3	Sept. 20	36	50	84	83	97	96

EFFECT OF IMMATURITY ON SHELLING PERCENTAGE

Shelling percentage was obtained at the time when the germination test was made. The grain was shelled from the ears and the ratio of the weight of grain to the total weight of ears was calculated. Shelling percentage increased from 25% in the early milk stage to 82% in the beginning glaze stage for the Golden Glow variety. A similar increase was obtained for Murdock, namely, 45% in the early milk stage to 85% in the beginning glaze stage. There was little difference in shelling percentage between the beginning of the glaze stage and the full dent stage.

EFFECT OF IMMATURITY ON GERMINATION

A germination test was made in February following harvesting. Corn which was harvested in the early milk stage germinated poorly. Weak sprouts developed from 14% of the Golden Glow kernels and from 75% of the Murdock. Kernels which were checked in development in the late milk stage germinated 74% and 87%, respectively. While the sprouts were stronger than those from kernels harvested in the early milk stage, they were not as strong as those from kernels harvested in later stages. Where development was checked in the dough stage, the germination was 99% and 97%, respectively. This was as high as for kernels harvested at later stages. Sprouts which developed from kernels at this stage were nearly as strong as those from kernels harvested at the beginning glaze and the full dent stages. There was little difference, if any, in germination between kernels harvested in the beginning of the glaze stage and those in the full dent stage.

INFLUENCE OF ADJACENT ROWS OF SOYBEANS ON ONE ANOTHER[1]

R. J. GARBER AND T. E. ODLAND[2]

In varietal experiments the influence of adjacent rows on one another may be marked. The effect of a tall or heavy-yielding strain adjacent to another strain has been studied particularly in the small grains and corn. During the last two years the writers have made a similar study with soybeans.

At the West Virginia Experiment Station the soybean varietal experiments are carried on in rows 18 feet long and 30 inches apart. Each variety is grown in four or more systemmatically distributed plats. Each plat consists of four rows. After discarding a foot of the end of each of the two inner rows the remainder of one of them is used for obtaining yield of seed and the remainder of the other for yield of forage. The seed rows, when ripe, are cut with a sickle and placed in a loosely woven burlap bag to dry. Each bag, containing the plants from one row, is hung in a well ventilated shed until late in the fall when the beans are threshed. The rows to be used for determining the forage yields are cut when the plants have sufficiently matured for hay. The green weight is taken immediately and at the same time a sample (approximately 4 kilograms) of each row is placed in a muslin bag which is hung in an artificially heated drying room maintained at a temperature of 45° to 55° C. The samples remain here until the excess moisture is driven off after which they are hung in a shed and allowed to become thoroughly air dry. All hay yields are expressed on an air-dry basis.

In carrying on the varietal experiments the border rows of each plat are ordinarily discarded, but in 1924 and in 1925 these rows were harvested and the yields determined the same as for the inner rows. The yields in 1924 in tons of air-dry hay per acre and in 1925 in bushels of seed per acre were determined for each border row. In addition to yield, the average height of the plants in each row was recorded. With these data it was possible to study the influence of yield and height of certain rows on adjacent rows. This was done in a manner similar to that used by Hayes and Arny[3] with small grains. The yield difference between the border rows of each plat was correlated with the height difference, and also with the yield difference of the adjacent rows.

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[1] Approved for publication as Scientific Paper No. 24, by the Director of the West Virginia Agricultural Experiment Station, Morgantown, W. Va. Received for publication May 3, 1926.

[2] Agronomist and Associate Agronomist, respectively.

[3] HAYES, H. K., and ARNY, A. C. Experiments in field technic in rod row tests. *In* Jour. Agr. Res., 11:399–419. 1917.

YIELD DIFFERENCE OF BORDER ROWS AND HEIGHT DIFFERENCE OF ADJACENT ROWS

The correlation of yield difference in tons of air-dry hay per acre between the border rows with height difference in inches between the adjacent rows in 1924 was not significant (r = + 0.007 ± 0.065). The differences (108 pairs) were correlated in a manner such that an appreciable influence of adjacent rows on border rows would be indicated by a negative correlation. It is apparent from the correlation coefficient obtained that relatively tall-growing varieties did not tend to depress the yields of varieties in adjacent rows.

In 1925 the yield difference in bushels of seed per acre between the border rows was correlated with the height difference in inches between the adjacent rows. Here, as in 1924, no significant correlation was found, the coefficient being — 0.090 ± 0.058. For this study there were 131 different pairs available.

YIELD DIFFERENCE OF BORDER ROWS AND YIELD DIFFERENCES OF ADJACENT ROWS

In a manner entirely analygous to that used for studying the interrelation of height and yield in rows side by side, a study was made of the influence of yield of adjacent rows upon yield of border rows. Here again, the differences were correlated so that an appreciable effect of the productivity of one row on that of an adjacent one would be indicated by a negative correlation. In 1924 the correlation coefficient obtained was + 0.049 ± 0.065, a constant which is not significant. The correlation surface for the data collected in 1925 is shown in Table 1. In this case a small but significant positive correlation coefficient (+ 0.213 ± 0.056) was obtained. The slight

TABLE 1.—*Correlation of yield difference in bushels between border rows with yield difference in bushels between adjacent rows in the soybean varietal experiment carried on in 1925.*

Yield difference between border rows	Yield difference between adjacent rows															
	−24	−21	−18	−15	−12	−9	−6	−3	0	+3	+6	+9	+12	+15	+18	
−12							1									1
−9																0
−6							4	1				1				6
−3		1			1		1	2	5	1	2		1			14
0	1	2	1		1	2	9	11	7	6	7	5		2	1	55
+3		1		1	1		3	6	5	9	4	3		1	1	35
+6					1			2	7	4	3	1				18
+9									1							1
+12																0
+15									1							1
	1	4	1	1	4	2	18	22	26	20	16	10	1	3	2	131

r = +0.213 ± 0.056

positive correlation is probably owing to soil heterogeneity. It shows that there was a tendency for a high-yielding border row to be associated with a high-yielding adjacent row.

CONCLUSION

Soybean varietal experiments carried on under the conditions and in the manner described did not show an appreciable effect of height or yield of one row upon the yield of an adjacent row. It appears, therefore, that under these conditions it is not necessary to grow border rows. Since alternate rows are harvested for forage, the distance remaining between the rows to be harvested for seed is great enough so that there is very little danger of mechanical mixtures.

FELLOWS ELECT

The preparation of the accompanying sketches represents a composite effort, and recognition of their cooperation is hereby accorded Messrs. Albrecht, Burlison, Farrell, Holbert, Hume, Johnson, McCall, Smith, R. S., Stevenson, Williams, C. G., and Worthen.

It might be stated further that the photographs were obtained through effort a little short of coercion, and be it particularly understood in this connection that the management of the JOURNAL is absolved from all responsibility for instigating the idea.—L. H. S. for the Executive Committee.

CARLETON ROY BALL

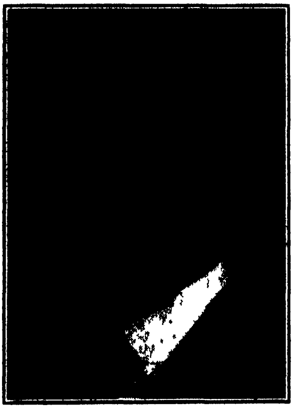
Carleton Roy Ball, Senior Agronomist in charge of cereal investigations, Bureau of Plant Industry, U. S. Department of Agriculture, is a charter member of the American Society of Agronomy. He has served the Society in the following positions of responsibility: Secretary from 1910 to 1914; editor of the Proceedings 1910–1912, and of the JOURNAL in 1913 and 1914; chairman of Committee on Terminology from 1913 to 1915 and continuing as a member of this committee to date, and president in 1916.

Dr. Ball received his bachelor's and master's degrees from the Iowa State Agricultural College and later this institution conferred upon him the degree of Doctor of Science.

Altho Dr. Ball has had a tremendous capacity for productive personal research, perhaps his greatest contribution to agricultural science has been his helpful influence on the quantity and quality of work of those with whom he has come in contact through cooperative relationship and the inspiration for worthy accomplishment imparted to those in the Office of Cereal Investigations.

He not only has continued to develop himself as a scientist during the past several years, but has made it possible for many other students of plant sciences to realize leadership in their respective fields. He has encouraged fundamental research and at the same time maintained a fine appreciation of the application of scientific data to the solution of present and future agronomic problems. He has coordinated in an unusual way the efforts of a large group of men and promoted effective cooperation between the United States Department of Agriculture and the majority of the State Agricultural Experiment Stations.

PERCY EDGAR BROWN



Percy Edgar Brown is the present secretary of the American Society of Agronomy, having served the organization in this position since 1920. Through his activities as secretary, he has carried on a large part of the work that has been done in recent years to build up and strengthen the Society.

Dr. Brown pursued his collegiate work at Rutgers College, which institution has conferred upon him the degrees B. S. in 1906, A. M. in 1909, and Ph. D. in 1912. He was Assistant Soil Chemist at Rutgers from 1906 to 1910. In 1910 he accepted a position at Iowa State College. Since 1914 he has been Professor of Soil Bacteriology, Chief in Soil Bacteriology and Chemistry, and Associate Director of the Soil Survey. Dr. Brown, through his work at Iowa State College, is widely known as a successful teacher, as a leading investigator in the field of soil bacteriology and chemistry, and as the author of many high class articles and bulletins.

LELAND EVERETT CALL

Leland Everett Call was graduated with a bachelor's degree in agriculture at Ohio State University in 1906, and received a master's degree at the same institution in 1912. Since 1907 he has been connected with the Kansas College and Station where he began as an Assistant in Agronomy and subsequently was head of the Department of Agronomy (1913–1925), Acting Dean and Director (1918), and Dean and Director since May 1925.

In 1918 to 1919 he did educational work in agronomy among the soldiers of the American Expeditionary Forces in Europe.

Besides his numerous miscellaneous contributions to the agricultural press, on soils and crops, Professor Call is co-author with H. L. Kent of a book, "Agriculture for the Common Schools of Kansas." Dean Call has been a member of the American Society of Agronomy since the year of its organization and has been active in its service as Assistant Editor of the JOURNAL for ten years; Chairman of Committee on Teaching Agronomy (1921); representative of the Society on the National Research Council (1921); representative in the American Association for the Advancement of Science (1925); and President (1922).

SIDNEY BURRITT HASKELL

Sidney Burritt Haskell, Director of the Massachusetts Agricultural Experiment Station, was born in Fargo, North Dakota. He was graduated from the Massachusetts Agricultural College in 1904. The following year he spent at the Hatch Experiment Station as assistant agronomist. In 1905 he returned to the Massachusetts Agricultural College where he served successively as Instructor, Assistant Professor, Associate Professor, and finally as full Professor.

In 1916, Professor Haskell resigned to become the director of the Soil Improvement Committee of the National Fertilizer Association, serving until 1920 when he was called back to Amherst to become the director of the Massachusetts Experiment Station.

Director Haskell has long been a member and an effective worker in the American Society of Agronomy. In 1923 he served the Society as its President.

JACOB GOODALE LIPMAN

Jacob Goodale Lipman is Dean of Agriculture in Rutgers College and Director of the New Jersey Experiment Station.

He was born in Russia, coming to the United States at the age of fourteen. He received his B.S. degree at Rutgers in 1898; his A.M. degree in 1900; his Ph.D. degree in 1903 at Cornell; and his D.Sc. degree in 1923 at Rutgers.

Dr. Lipman is a recognized national and international leader in biochemical and bacteriological thought and research. Nitrogen-fixing and sulfur bacterica and nitrogen economy are subjects which have elicited his special interest. His many scientific publications form a long list. His literary activities, however, are not confined to his own writings for he has rendered distinguished service as Editor of Soil Science, as Associate Editor of the Journal of Agricultural Research, and as Assistant Editor of the JOURNAL OF AMERICAN SOCIETY OF AGRONOMY. He takes a keen interest in graduate students and has built up an active graduate department at his institution.

In recent years he has given much attention to the organization of the soil scientists of the world and is now President of the International Society of Soil Scientists.

In the American Society of Agronomy, Dr. Lipman served nine years on the editorial staff, has been a vice-president three terms, and in 1921 he was president of the organization.

THOMAS LYTTLETON LYON

Thomas Lyttleton Lyon is Professor of Soil Technology in the New York State College of Agriculture at Cornell University. He was reared in Pennsylvania. He received his college training at Cornell, completing the course in chemistry in 1891 and receiving his doctorate in 1904, to which preparation was added a year of study at Gottingen, Germany. Fifteen years were spent in chemical, agronomic, and administrative work at the University of Nebraska. At the end of this period he returned to his alma mater as Professor of Soil Technology.

He is author of "Soils and Fertilizers" and senior author of "Soils, Their Properties and Management," and of "The Nature and Properties of Soil." The contributions resulting from research work have had to do largely with the nitrogen problem.

Always a loyal member of the American Society of Agronomy, he served as secretary from 1907 to 1909, and as president for the year 1918–19. In addition to discharging the duties of these responsible offices, Dr. Lyon has given long years of service to the Society in his capacity of associate editor of the JOURNAL.

MERRITT FINLEY MILLER

Merritt Finley Miller is Professor of Soils, Assistant Dean of the College of Agriculture, and Assistant Director of the Experiment Station of Missouri. His connection with the institution dates from 1904, when he became Professor of Agronomy, following preparation through a degree in agriculture from Ohio State University, a master's degree from Cornell, a year of soil surveying with the federal bureau, and two years as instructor at his alma mater. As Professor of Agronomy he spent a year in travel and study in Europe.

Professor Miller's main interest has been in the subject of soils, to the knowledge of which he has made worthy contributions. He has been a moving spirit in the American Soil Survey Association, serving as its first president.

His connection with the American Society of Agronomy dates practically from its inception, his name appearing among the charter members, and his leadership in its activities is attested by his election to the office of first vice-president for two terms and finally, in 1924, to the presidency of the organization.

CHARLES VANCOUVER PIPER

Charles Vancouver Piper, deceased, was for twenty years in charge of the Office of Forage Crops Investigations in the United States Department of Agriculture.

He was born in British Columbia. He graduated from the University of Washington, took a master's degree at Harvard, and received the D. Sc. degree from Kansas State University.

Doctor Piper was a highly trained and proficient botanist and in this capacity he gave a life rich in service to agriculture. In addition to a long list of miscellaneous scientific contributions he is author and co-author of a number of books among which perhaps the best known is the excellent text-book, "Forage Plants and Their Culture." Among his outstanding achievements may be mentioned the introduction into this country of Sudan grass, the value of which has been estimated in millions of dollars annually.

Piper possessed an unusually attractive personality. The high esteem in which he was held by his associates, not only for his ability as a scientist and as an executive, but also for his amiable personal qualities, has been testified to from all quarters.

With his characteristic zeal Dr. Piper entered wholeheartedly into the work of the American Society of Agronomy and he has left a record of long and active service in the organization. The more important work to be mentioned in this connection is his three years of service as chairman of the Committee for Standardization of Field Experiments, ten years as chairman of the Committee on Terminology, twelve years as associate editor of the JOURNAL, and a term as president of the Society.

CLYDE WILLIAM WARBURTON

Clyde William Warburton entered the Office of Farm Management, Bureau of Plant Industry, U. S. Department of Agriculture, in 1903; was in charge of oats investigations in the Office of Cereal Investigations from 1907 to 1920 (except for seventeen months with the Webb Publishing Company of St. Paul); and was in charge of cereal agronomy experiments from 1921 until he became Director of Extension in 1923.

He graduated from Iowa State in 1902 and received an honorary doctorate there in 1925. He is the author of numerous bulletins on oats and joint author of the textbook, "Field Crops."

The American Society of Agronomy is deeply indebted to Dr. Warburton for many years of faithful and arduous service especially as secretary of the Society from 1915 to 1917 and as editor of the JOURNAL from 1918 to 1921. In 1923 he served on the Committee of Registration of Varieties and in 1925 was president of the organization.

ROSCOE WILFRED THATCHER

Roscoe Wilfred Thatcher, present editor of the JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY, has had a rich and varied experience in responsible service. He was graduated from the University of Nebraska, took the master's degree there, and received from the same institution the degree of Doctor of Agriculture. In 1925 he was awarded the degree of LL.D., by Hobart College, for distinguished service to agriculture.

His first official appointment began in 1899 as Assistant Chemist in the Nebraska Experiment Station. Three years later he transferred his activities to the State College of Washington where he advanced to the position of Chemist and Professor of Agricultural Chemistry, finally becoming Director of the Station. In 1913 he was called to the University of Minnesota to be Professor of Plant Chemistry and later was made Dean of the College and Director of the Station.

He was appointed to his present office as Director of the New York State Agricultural Experiment Station in 1921, and two years later there was added to his responsibilities the directorship of the Cornell Experiment Station.

A noteworthy fact that attests either the genius of an organizer, or the possession of a tremendous energy reserve, or both, is that along with his heavy executive responsibilities Dr. Thatcher has been able to accomplish personally much productive scientific work of high order.

Dr. Thatcher is a charter member of the American Society of Agronomy. His outstanding activities in the organization include a term as vice-president, a term as president, nine years on the editorial staff as assistant editor for Crop Chemistry, and finally, his service since 1922 as editor of the JOURNAL.

CHARLES EMBREE THORNE

Charles Embree Thorne has been called the "Dean of Agricultural Experiment Station Directors." For thirty-four years he was Director of the Ohio Station.

Thorne was born in Greene County, Ohio. He was reared on the farm. He attended Antioch College and was awarded the honorary degree of Master of Agriculture by Ohio State University.

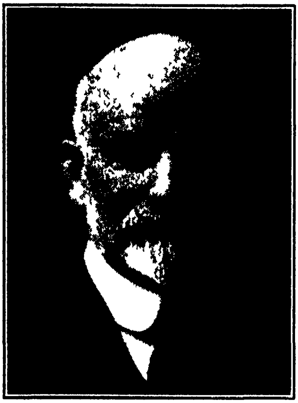
In 1877 he became Farm Manager at Ohio State University. In 1881 he was made Associate Editor for Farm and Fireside. He was appointed Director of the Ohio Agricultural Experiment Station in 1887, in which capacity he served until 1921, when he retired from the directorship and was made Chief in Soil Fertility.

Under his direction, the famous soil experiment plats at Wooster attained their world-wide reputation, contributing an untold wealth of information for the advancement of the science of soils. Indeed, these plats have been referred to as the "Rothamsted of America."

In 1915 Director Thorne was elected president of the Association of American Agricultural Colleges and Experiment Stations and during the same year he served as President of the Society for the Promotion of Agriculture.

Director Thorne has served the American Society of Agronomy in various capacities. He was on the Membership Committee in 1913 to 1915, was appointed assistant editor of the JOURNAL for 1913, was elected first vice-president 1914, and the following year was promoted to the Presidency.

CHARLES AMBROSE ZAVITZ



Charles Ambrose Zavitz has for many years held the position of Professor of Field Husbandry and Professor of Field Experiments of Ontario Agricultural College, Guelph, Ontario. He is a native Canadian, reared on an Ontario farm. He received his college training at the University of Toronto, attaining the degree of B. S. A. in 1888. In 1916 the degree of D. Sc. was conferred upon him.

The work of Zavitz is characterized by a steadfastness of purpose and continuity of effort, such that the man as well as his work enjoys the profound respect of colleagues in his field.

Among the noteworthy services that he has discharged may be mentioned the following: Vice-president of the Canadian Seed Growers Association; Secretary of the Ontario Agricultural and Experimental Union; Vice-president, American Society of Agronomy; Director of Cooperative Experiments in Ontario; Delegate to the Second Convention on Hybridization and Plant Breeding, New York, 1902; same in London, 1906.

In the American Society of Agronomy, Professor Zavitz has been Vice-president for two terms and he served four years as assistant editor of crop production for the JOURNAL.

AGRONOMIC AFFAIRS

SUMMER MEETINGS OF THE SOCIETY

The Western Branch of the American Society of Agronomy will hold its annual meeting July 20, 21, and 22, at the Utah Agricultural Experiment Station, at Logan, Utah.

The Corn Belt Section of the Society will hold its summer meeting at University Farm, St. Paul, Minnesota, on July 15, 16, and 17. The program provides for field inspections and study of the work at the Minnesota Station in cereal improvement, crop rotations, forage crop studies, plant breeding, plant pathology, soil treatment, and plant sterility and fertility studies.

NEWS ITEMS

Dr. George R. Lyman, Dean of the College of Agriculture of the University of West Virginia, and formerly pathologist in the Bureau of Plant Industry of the United States Department of Agriculture, died at his home in Morgantown, W. Va., on June 7, after an illness of nearly a year.

A. F. Kidder has resigned as Agronomist of the Louisiana Agricultural Experiment Station, effective June 15, in order to accept a position as cotton breeder for the growers of the Canete Valley in Peru. H. V. Geib, Assistant Professor of Agronomy in the Louisiana State University, has also resigned and will go with him as assistant. Their new address will be 7 Sr. Pedro G. Beltram Apartado 485, Lima, Peru. They plan to sail from New York on July 22.

Dr. A. P. Dachnowski, of the Office of Soil-bacteriology Investigations of the United States Bureau of Plant Industry, is in Europe for the present summer for the purpose of making comparative studies of European peat areas with those of this country. He will visit several experiment stations and make a study of investigations which are in progress in peat-land agriculture.

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SYMPOSIUM ON "CONTROLLING THE QUALITY OF CROPS"

Leader: H. L. Walster, Professor of Agronomy and Soils and Chairman of the Department of Agronomy, North Dakota Agricultural College, Fargo, N. D.

1. "Controlling Quality of Crops." H. L. Walster.

2. "Controlling the Quality of Wheat Through Rotation and Proper Crop Sequence." R. I. Throckmorton, Kansas Agricultural Experiment Station.

3. "The Influence of Certain Soil Amendments upon the Quality of Soft Red Winter Wheat in Ohio." L. E. Thatcher, Ohio Agricultural Experiment Station.

4. "Breeding Wheat for High Protein Content." J. A. Clark, Office of Cereal Investigations. Bureau of Plant Industry, U. S. Department of Agriculture.

5. "The Effect of Rotation, Fertilizers, and Soil Amendments on the Quality of Cotton Fibre." (By title only) M. F. Funchess, Alabama Agricultural Experiment Station.

6. "The Relation of Seeding Practices to Crop Quality." T. A. Kiesselbach, Nebraska Agricultural Experiment Station.

7. "The Influence of Time of Cutting upon the Quality of Crops." A. C. Arny, Minnesota Agricultural Experiment Station.

I. CONTROLLING QUALITY OF CROPS[1]

H. L. Walster[2]

The producer of two blades of grass where but one blade grew before has been called a benefactor of mankind; but in these days of much talk about over-production, doubt has arisen in many minds as to the beneficence brought about through increases in production. It has seemed timely, therefore, to focus our attention just a bit more narrowly upon the need for a better blade of grass. In suggesting this symposium on the control of quality in crops my purpose is not necessarily to suggest that we lay any less emphasis upon the control of yield, but that in all production studies, and in all experimentation related thereto, we, as agronomists, should place relatively more emphasis upon the quality of the crop than has been our custom.

Quality in crops may be defined as special suitability for the specific purpose for which the crop is utilized. Our discussions will take on a clarity not otherwise obtainable if we will keep constantly in mind what we are trying to control. A discussion, for example, of controlling the quality of wheat should keep in mind that wheat is used for such diverse purposes as bread, pastry, and alimentary pastes, and that the wheaten product used for each of these special purposes must have specific qualities. These discussions should recognize also that whenever any other substance enters into a manufactured product than the particular raw product under discussion, that this other substance has its effect upon the quality of the manufactured product. Let me go to the bread basket for an illustration. In addition to wheat flour, bread contains milk or water, added fats, salt, yeast, and frequently yeast foods. The quality of the loaf of bread is the resultant of the chemical, physical, and biological interplay of these several components. Component "wheat flour" may be kept constant both with respect to quantity and quality, and yet through variations in other components a quite different loaf of bread may result. Or component "wheat flour" may vary as to quality, and yet the resulting loaf may still be brought up to standard, within limits, through a controlled variation of the other components used.

Take another important product largely used for human food—the potato. What constitutes quality in a potato? A potato may be ideally adapted for baking, but be quite unsuitable for boiling, and wholly unusable for "warming over". It is clearly within the province of the research agronomist to try to discover the conditions which determine these variations in quality in the potato, and to attempt to devise methods which will help insure the production of a standard product. It is equally clear that the extension agronomist is called upon to make these facts part of the useful equipment of the potato producers. But what is not so clear is this fact which sticks out like a sore thumb in any discussion on crop quality—to wit: Whose business is it to teach the still uninformed consuming public that there are "potatoes" and "potatoes;" some good bakers, some excellent for fancy potato dishes, and some that cannot even be too greatly spoiled by the all-American custom of "boiling." Not only must a large part of the consuming public be made aware of differences in the quality of good products; but they need to be made aware that in the producing or sorting out from mass production, potatoes or any other product of high quality, the farmer is performing a service over and above that performed in producing products of average or low quality and that he should, therefore, be rewarded accordingly.

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[1] Paper read in introducing the symposium on "Controlling the Quality of Crops" at the meeting of the Society held in Chicago, Ill., November 17, 1925.

[2] Agronomist, North Dakota Agricultural Experiment Station, State College Station, Fargo, N. D.

Very frequently the producer himself needs to be made aware of the fact that his product has a value much above the ordinary. Recent investigations by the North Dakota Experiment Station show that there are fundamental weaknesses in the usual physical methods employed in the grading of hard red spring wheats, and that as a result the producer who fails to have these physical methods supplemented by chemical tests for protein, for example, may fail to receive the true value for his product when there exists a special demand for high protein wheat. Wheat purchase based upon a chemical analysis for total protein is becoming, therefore, a common practice in the Northwest. Such chemical tests will probably not always measure the true value of the wheat, and the time is not far distant when we shall have to apply physico-chemical tests and perhaps even the baking test.

FACTORS INFLUENCING QUALITY

The factors influencing crop quality may be classified under two main heads, *viz.*, internal and external. The leading internal factor is undoubtedly the genetic constitution. This factor is amenable to control within limits. That these limits may vary widely and that the possibilities of the improvement of a crop plant through selection and by hybridization are enormous, we need only cite the case of the sugar beet which in about 75 years time has been raised from an inferior beet having about 8.5% sugar to a beet frequently containing more than 20% sugar, a task largely accomplished by chemical, physical, and physiological selection.

If the quality of the sugar beet has been enhanced three fold, should the agronomist feel any hesitancy in calling upon his colleague, the plant breeder, to double the protein content of wheat or to accomplish even more with our great bread crop? A second group of internal factors which influence the quality of a crop as well as the yield are those internal factors determining germination and vigor of growth. This group of factors are even now largely within the control of the farmer through proper seed selection.

External factors influencing crop quality may be considered under three main heads: (1) Climate, (2) soil, and (3) husbandry.

CLIMATE

Climate is not within the control of the farmer, yet the peculiar quality given to a crop by a given set of climatic conditions may make that crop of particular usefulness to the farmer as well as the consumer in another set of climatic conditions. No self-respecting North Dakota farmer, having any regard for his internal economy, will deliberately choose to grow Triumph potatoes for home consumption—yet he does grow them for shipment to the seed trade of Louisiana and other southern states to satisfy their demand for a potato for the early plantings whose resulting crops of early new potatoes are again shipped to North Dakota and purchased by the fortunate few who can afford to consume that particular kind of subterranean gold. The climatic conditions of North Dakota and other northern states lock up in the potato capacities for growth not obtainable under other conditions.

Certain crops are grown under widely varying climatic conditions—potatoes and wheat are good examples—and these variations produce tremendous differences in quality which are usually much larger than can be produced through changes in soil, in husbandry, or in variety, yet we must not look upon the climatic control as all powerful for changes are brought about through soil amelioration, husbandry, and plant breeding.

SOIL

The physical characteristics of the soil have a profound influence upon the quality of crops, and great stress is laid upon this fact in most of our text books upon soils. The student is informed, for example, that the center of hard red spring wheat production is in the Red River Valley, because the fine texture and large amount of organic matter in that soil makes it ideally adapted to wheat production. Every soil survey report that he picks up solemnly announces that its *raison d'etre* is the physical classification of the soil in order that crops may be selected which are adapted to the soil.

But shifting economic conditions, or a changed "ecos" with respect to weed, disease, and insect pests, compel the Red River Valley farmer, for example, to grow on a single farm crops requiring such widely diverse conditions as wheat, corn, potatoes, alfalfa, sugar beets, sweet clover, red clover, etc. When the wheat farmer on the Fargo clay starts to grow potatoes, his only chance at improving either the yield or the quality of his potato crop is to forget all academic discussions about crop adaptation and to practice soil adaptation.

The late Professor C. G. Hopkins, with his usual ability to get at the fundamentals of a situation, was perhaps the first soil scientist in this country who dared to say that soils must be changed, that is, adapted to crops. He recognized clearly enough that the farmer on the land must be taught to cope with the soil situation as he finds it, and the introduction of a variety of crops, in short, diversification, is one of our most commonly recommended specifics for the farmer's and the farm's economic ills. Soils are not chosen, if indeed they ever were, in any large or important sense. They must be modified, within limits, to meet the demands of the crops which climatic and economic conditions determine we must produce. Where diversity of soil exists on a particular farm, or within the comparatively narrow limits of a community, there can be more choice of soil than is possible in the great areas of staple production where wide diversity is not so common.

HUSBANDRY

The major purpose of this symposium is to call attention to the degree of control over crop quality which we may exercise through the practice of good husbandry. Using the term husbandry in a rather wide sense, we may say that it includes those practices which ameliorate the soil and those practices which enable the seed and the growing crop in the properly conditioned soil to make the fullest and best use of its environmental conditions. The first group of practices include rotation, fertilization, moisture conservation, etc.; the second group, seeding practices, such as dates, rates, depths, etc., harvesting practices, and storage practices. The scope of this symposium is so broad that it will be possible for me to refer to only a small part of the evidence relative to the various practices. Other members of the Society will summarize the evidence from several of these different points of view.

Brief reference to some data[3] from the departments of Agronomy and Cereal Chemistry at the North Dakota Experiment Station will serve to emphasize the degree of control exercised by simple crop rotation upon some factors of quality in a single variety of one crop, namely, Kota wheat. Two rotations are compared. In the first rotation of oats, wheat, red clover, flax, proso, and mangels (or sugar beets), the wheat follows oats; while in the second rotation of potatoes, wheat, barley, and red clover, the wheat follows potatoes. Tables 1 and 2 show the comparative yields per acre on the two rotations, and the placings of the product with respect to four "quality" ratings, namely, bushel weight, percentage of straight flour, percentage of protein, and loaf volume.

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[3] I am indebted to C. E. Mangels, Cereal Chemist at the North Dakota Experiment Station, for furnishing the milling and baking data used in this discussion.

TABLE 1.—*Influence of crop rotation on yield, bushel weight, and percentage of straight flour of Kota wheat grown on Fargo clay.*

Sequence	Year	1921	1922	1923	1924	Average, 1921–24
Wheat after oats	Yield, bushels per acre	14.6	24.3	21.1	32.9	23.2
	Bushel weight, pounds	59.5	62.0	59.8	62.5	61.0
	Percentage of straight flour	72.5	72.9	75.1	77.7	74.6
Wheat after potatoes	Yield, bushels per acre	13.6	21.1	23.1	42.3	25.0
	Bushel weight, pounds	55.5	58.5	56.4	62.4	58.2
	Percentage of straight flour	69.9	74.5	73.1	77.1	71.2

From the point of view of the usual methods of grading which lays large emphasis upon the test weight, the wheat after potatoes was of low quality in three out of the four years as compared to wheat after oats. Table 2 shows, however, that the flour from wheat after potatoes was uniformly of high protein content, and that in two out of four years it produced significantly larger loaves of bread.

TABLE 2.—*Influence of crop rotation on percentage of protein in the straight flour and the volume of loaf baked from 340 grams of straight flour of Kota wheat grown on Fargo clay.*

Sequence	Year	1921	1922	1923	1924	Average, 1921–24
Wheat after oats	Percentage of protein	11.59	9.36	11.03	10.16	10.54
	Volume of loaf in cc.	2,538	1,938	2,185	2,143	2,201
Wheat after potatoes	Percentage of protein	15.69	13.83	14.31	11.91	13.94
	Volume of loaf in cc.	2,587	2,374	2,606	2,015	2,396

Many other rotations might have been compared, but the two comparisons given illustrate strikingly some very definite differences in crop quality attributable to differences in the crop rotation.

2. CONTROLLING THE QUALITY OF WHEAT THROUGH ROTATION AND PROPER CROP SEQUENCE[1]

R. I. THROCKMORTON[2]

The effect of cropping systems on the quality of wheat has been studied as a part of the soil fertility work at the Kansas Experiment Station. The first results from the project were secured in 1911; but since several years were required to get the rotations established, it was not until 1916 that wheat was harvested from plats that had previously grown all of the crops represented in the various systems of cropping. This condition did not occur again until 1919. Since then results have been secured each year from all systems.

CROPPING SYSTEMS

The first cropping system, known as the 16-year rotation, consists of four years of alfalfa, one year of corn, and two years of wheat; the two years of wheat and one year of corn alternating for 12 years. The second system is the same as the first, but an application of 5 tons of manure per acre is made every third year. The third cropping system is the same as the second, except that brome grass is substituted for alfalfa. A fourth system, known as the three-year rotation, consists of corn, cowpeas for hay, and wheat. The fifth is two years of corn and one of wheat. The sixth method is continuous wheat production. Data contained in this paper from systems one, four, and six are the averages from four plats under each treatment, while that for the other three are each from one plat.

EXPERIMENTAL RESULTS

The quality factors to be considered in this paper are the weight of wheat per bushel and the protein content of the grain. Protein percentages are expressed on the basis of 12.5% of moisture in the grain.

YIELDS

In studying the factors that influence the quality of a crop the effect on the yield should not be overlooked. Table 1 shows that the average yield of wheat has been the highest, 25.1 bushels per acre, in the rotation of brome grass, corn, and wheat where manure was used. The second highest yield, 21.4 bushels per acre, was secured from the alfalfa, corn, wheat rotation where manure was used. The relatively high yield in the first case may be accounted for in part by the fact that the yield of brome grass hay was very low, while high yields of hay were secured from the corresponding alfalfa plat and also to more lodging and greater susceptibility to burning after alfalfa. Although wheat yields are higher after brome grass than after alfalfa, the latter system is to be preferred because of the relatively high value of the alfalfa crop. The average yield of wheat in the alfalfa, corn, wheat rotation without manure was 19.3 bushels per acre, or 2.1 bushels less than in the same rotation with manure. The average yield of wheat from the corn, cowpeas, wheat rotation was almost identical with that from the alfalfa, corn, wheat rotation. These results illustrate the possible value of a crop like cowpeas to maintain wheat yields where alfalfa is not adapted. The two years of corn and one of wheat system produced an average yield of 14.4 bushels per acre, which is 1.4 bushels less than was received from continuous wheat production. Wheat grown continuously has the advantage of an early-prepared seedbed, while wheat following corn is seeded on disked ground which is frequently dry.

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[1] Paper read as a part of the symposium on "Controlling the Quality of Crops" at the meeting of the Society held in Chicago, Illinois, November 17, 1925. Contribution No. 161, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans.

[2] Agronomist.

TABLE 1.—*Effect of cropping system on the yield of wheat.*

Cropping system	Yield, bushels per acre							
	1916	1919	1920	1921	1922	1923	1924	Average
1. Sixteen-year rotation	18.5	20.3	11.0	15.3	34.4	19.5	16.1	19.3
2. Sixteen-year rotation and manure	26.3	24.6	13.8	17.7	34.7	19.2	13.2	21.4
3. Sixteen-year rotation, brome grass substituted for alfalfa, and manure	33.1	29.7	19.1	16.8	31.7	32.0	13.1	25.1
4. Three-year rotation.	16.7	19.6	9.1	21.4	26.7	26.2	14.6	19.2
5. Corn two years, wheat one year....	13.6	24.0	12.4	8.4	18.8	15.0	8.3	14.4
6. Continuous wheat..	6.4	19.2	11.3	9.6	30.4	21.4	12.2	15.8

PERCENTAGE OF PROTEIN

The effect of cropping systems on the protein content of wheat is shown in Table 2. The average percentage of protein[3] is higher in the wheat produced in the alfalfa, corn, wheat rotation than in any of the other systems. The addition of manure in this rotation caused a slight decrease in the protein content, probably due to the much higher yields secured. When brome grass was substituted for alfalfa the average protein content of the wheat was reduced 3%. This reduction may possibly be due to the higher yield of wheat after the brome grass, or to a lower nitrate content of the soil, or to both.

[3] The protein determinations were made by the Department of Milling Industry, Kansas Agricultural Experimental Station.

In the corn, cowpeas, wheat rotation the protein content of the wheat averaged only 12.8%, although there was a legume in the rotation. The low protein content in this case is possibly due to the short period of time elapsing between harvesting the cowpeas and seeding the wheat, this time not being sufficient for nitrification to take place to any great extent. The protein content of wheat in the two years of corn and one year of wheat system has averaged only 12.7%. This low protein content is no doubt due to the lack of a legume and to the short period of time between harvesting the corn

TABLE 2.—*Effect of cropping system on the protein content of wheat.*

Cropping system	Percentage of protein on 12½% moisture basis							
	1916	1919	1920	1921	1922	1923	1924	Average
1. Sixteen-year rotation	14.9	15.8	21.3	12.8	11.9	15.1	15.0	15.3
2. Sixteen-year rotation and manure.......	14.9	15.0	20.8	13.3	10.9	15.8	14.9	15.1
3. Sixteen-year rotation, brome grass substituted for alfalfa, and manure...........	12.5	12.7	15.4	11.9	10.2	10.7	11.5	12.1
4. Three-year rotation.	13.0	13.3	14.4	13.1	11.7	11.4	12.5	12.8
5. Corn two years, wheat one year....	12.6	11.3	15.6	14.4	11.1	12.2	11.4	12.7
6. Continuous wheat..	13.3	13.7	17.0	16.5	13.0	11.8	14.1	14.2

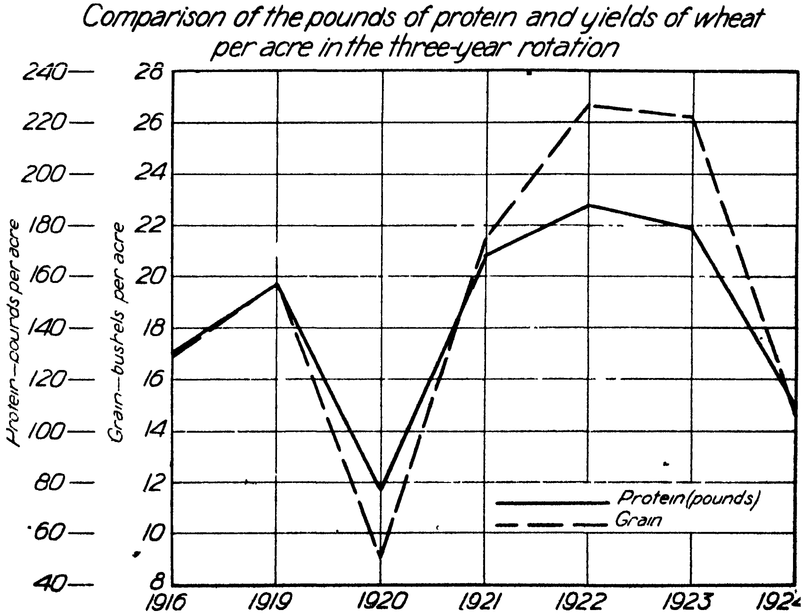

FIG. 1

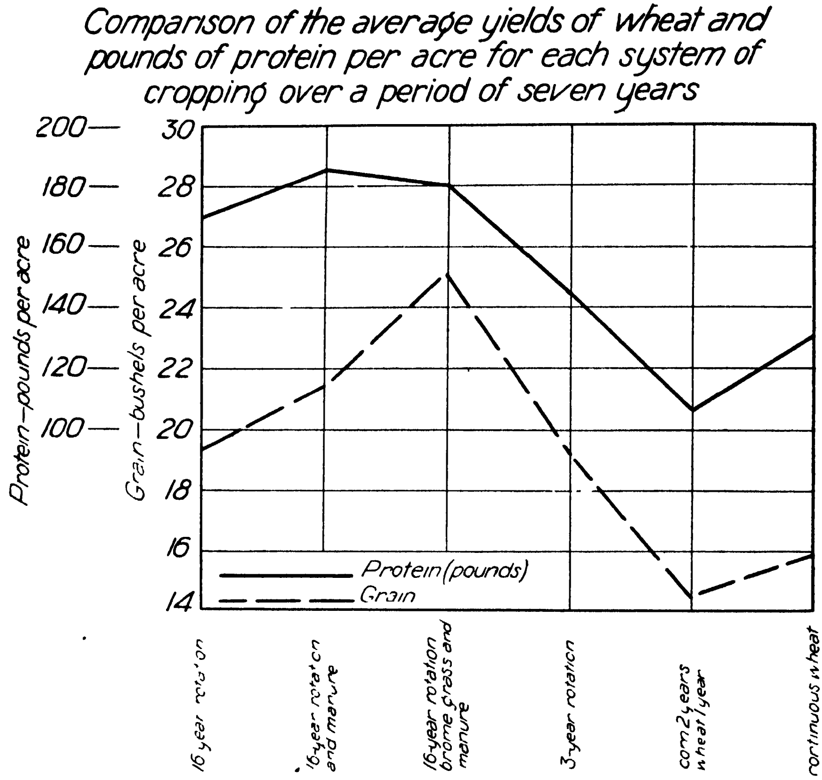

FIG 2

and seeding the wheat. Not only is the time for nitrification quite limited but the soil is usually very dry.

Continuous wheat production has resulted in a relatively high protein content. This is to be expected because the land is plowed early and there is sufficient time for nitrate accumulation. The low yields secured under this system also favor a high protein content of the crop.

POUNDS OF PROTEIN PER ACRE

The pounds of protein produced per acre (Table 3) should be considered in studying the quality of the crop because it combines yield and protein content. In the 16-year rotations with alfalfa and manure and with brome grass and manure the protein produced averaged 185.3 and 180.1 pounds per acre, respectively. The higher yield of the latter was overbalanced by the higher protein content of wheat grown in the former system. In the 16-year rotation with alfalfa and no manure the average number of pounds of protein produced per acre was 169. This lower production is due to the decreased yield. In the three-year rotation an average of 144.2 pounds of protein were produced per acre, while on the continuous wheat plats the average production was 130.1 pounds per acre. The high yields and relatively low protein content in the former were practically balanced in the latter by the high percentage of protein in the grain. The lowest average production of protein, 106.6 pounds, was in the two years of corn and one of wheat system. This is due to a combination of low percentage of protein and low yield.

TABLE 3.—*Effect of cropping system on the amount of protein produced.*

Cropping system	Pounds of protein per acre of wheat							
	1916	1919	1920	1921	1922	1923	1924	Average
1. Sixteen-year rotation	165.4	192.4	140.6	117.5	245.6	176.7	144.9	169.0
2. Sixteen-year rotation and manure	235.1	221.4	172.2	141.3	226.9	182.0	118.0	185.3
3. Sixteen-year rotation, brome grass substituted for alfalfa, and manure	248.3	226.3	276.5	120.0	194.0	205.4	90.4	180.1
4. Three-year rotation.	130.3	156.4	78.6	168.2	187.4	179.2	109.5	144.2
5. Corn two years, wheat one year	102.8	162.7	116.1	72.6	125.2	109.8	56.8	106.6
6. Continuous wheat	51.1	157.8	115.3	95.0	237.1	151.5	103.2	130.1

There is a very close correlation between the yield of wheat and pounds of protein produced per acre every year in each cropping system. This correlation is illustrated in Fig. 1, which shows graphically the annual yields of grain and pounds of protein produced in the three-year rotation. There is also a close correlation between the

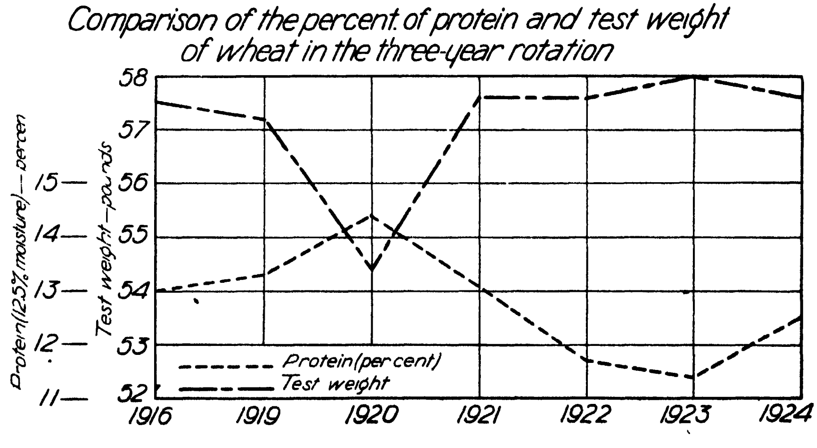

FIG. 3

average number of pounds of protein produced per acre and the average yields of wheat per acre (Fig. 2). It appears from these correlations and the data that have been presented that high yields are frequently associated with low protein content, while low yields may or may not be associated with high protein content depending on the rotation and crop sequence.

TEST WEIGHT OF WHEAT

Table 4 shows the annual and average test weights of wheat from each system of cropping Test weight has varied to a marked extent with seasonal conditions, especially in those rotations containing alfalfa. The most consistent test weights have been from the three-year rotation and from the one consisting of two years of corn and one of wheat. The highest average test weight was from the brome grass plat, while the lowest test weights were from the systems containing alfalfa. The average test weight of wheat from the three-year rotation and from the two years of corn and one of wheat was 56 8 pounds

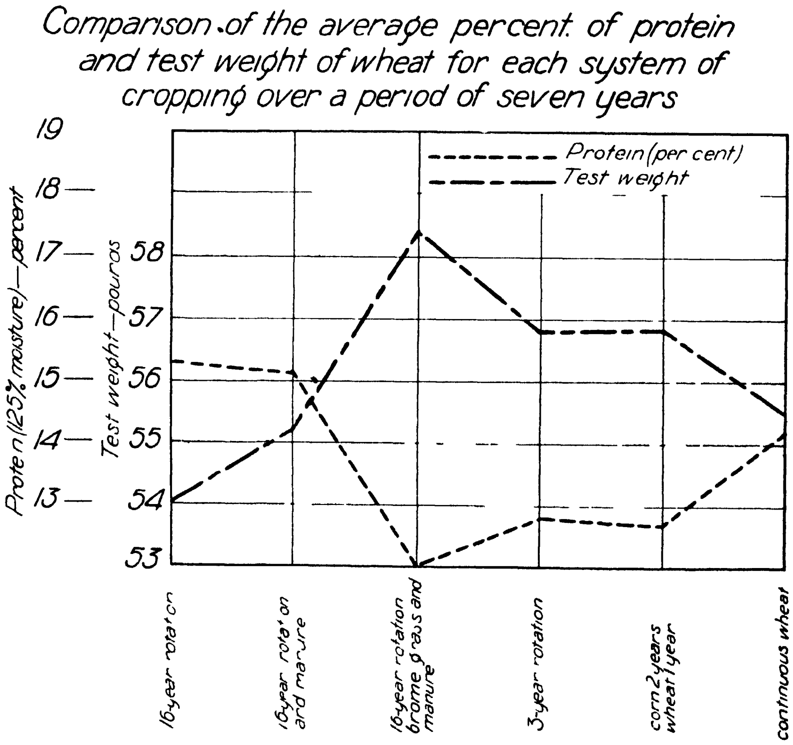

FIG 4

in each case. Where wheat has been grown continuously the average test weight has been 55.5, or almost as low as for wheat grown in rotation with alfalfa. It will be noted that there is no correlation between yields and test weights. There is, however, a negative correlation between test weight and percentage of protein. This is illustrated in Figs. 3 and 4 which show the test weight and percentage of protein for each year from the three-year rotation and the averages for all years for each rotation, respectively. This correlation is probably due to the fact that plump grain is often low in protein, whereas a shriveled kernel is usually high in protein.

TABLE 4.—*Effect of cropping system on the test weight of wheat.*

Cropping system	Test weight in pounds							
	1916	1919	1920	1921	1922	1923	1924	Average
1. Sixteen-year rotation	55.8	50.4	50.1	57.1	58.3	48.4	57.6	54.0
2. Sixteen-year rotation and manure.......	56.0	51.1	53.0	58.0	58.2	49.3	60.6	55.2
3. Sixteen-year rotation, brome grass substituted for alfalfa, and manure...........	60.0	55.5	57.2	58.5	58.4	57.8	61.1	58.4
4. Three-year rotation.	57.5	55.2	54.4	57.6	57.6	58.0	57.6	56.8
5. Corn two years, wheat one year....	59.0	56.3	54.5	56.0	57.8	56.1	57.7	56.8
6. Continuous wheat..	56.0	52.2	56.0	54.4	56.9	56.1	56.9	55.5

3. THE INFLUENCE OF CERTAIN SOIL AMENDMENTS UPON THE QUALITY OF SOFT RED WINTER WHEAT IN OHIO[1]

L. E. THATCHER[2]

Numerous investigators during the past three-quarters of a century have noted the influence of climate upon the composition of wheat. Lawes and Gilbert (8)[3] noted the effect of long and short ripening periods upon the percentage of nitrogen and plumpness of kernel, a long ripening period resulting in plump kernels with low percentage of nitrogen and a short period giving reverse results. Bailey (5), cites no less than 28 investigators who have reported experiments and

[1] Paper read as a part of the symposium on "Controlling the Quality of Crops" at the meeting of the Society held in Chicago, Ill., November 17, 1925. Contribution from the Department of Agronomy of the Ohio Agricultural Experiment Station, Wooster, O.

[2] Associate Agronomist.

[3] Reference by number is to "Literature Cited," p. 647.

observations on the effect of environmental conditions, principally moisture, on the physical and chemical composition of wheat, not including the 19 investigators who have reported the results of irrigation experiments.

In summarizing the results of these numerous investigations, Bailey concludes that "Cool summers with high rainfall and relatively long growth period result in the grain of wheat being high in percentage of starch and low in percentage of protein. Hot, dry summers, on the other hand, result in the production of wheat having a high percentage of protein. In general, the amount of rainfall during that period which immediately precedes ripening is responsible for the rate of starch deposition in the kernel, and consequently for the relative protein content. Climatic conditions are responsible for greater variations in the composition of wheat than are other factors, with the possible exception of irrigation."

Any discussion of the influence of soil amendments upon the quality of Ohio wheat will need to be carried on with the above limitations of climate in mind.

The red winter wheat crop of Ohio is classified, according to Federal standards, as "soft red winter," the characteristics of which are determined largely by climatic factors irrespective of variety or soil treatment.

The average annual rainfall in Ohio for a 34-year period is 38.03 inches. May, June, and July are the rainy months, 30% of the entire annual precipitation falling in this three-month period. The bulk of the hard winter wheat of the United States is grown with less than an annual rainfall of 35 inches and with comparatively dry summers.

That the selection of varieties may give a certain range of protein values to soft red winter wheat has been demonstrated beyond question, and any one familiar with the results of breeding types for high protein content would hesitate to place a limit to possible results secured in this way.

The results of many experiments in which the protein content has been increased through the application of nitrogenous fertilizer to the soil or nutrient solution indicate that herein may lie a practical means of controlling the quality of wheat also. It seems obvious that this may be more easily accomplished when climatic factors are in harmony than when otherwise.

There are certain sections of the United States where a soft wheat of low protein content of rather inferior quality is the predominating type. Here it might be desirable to increase the protein content and improve the quality. So far as Ohio is concerned, however, the problem of protein content has been solved to the satisfaction of both the producer and the consumer. This has been accomplished through vigorously campaigning against the growing of inferior varieties and through the introduction of better sorts.

As a result, between 45 and 50% of the entire winter wheat acreage in Ohio at the present time is the Trumbull variety; a pure-line selection from the Fultz, developed by the Ohio Experiment Station. The dry gluten content of flour made from Trumbull wheat is about 9%, being near the average of 54 varieties tested at Wooster. The gluten quality is classified as strong. Corbould (6) places Trumbull in the semi-hard group of Ohio soft red winter wheats. It is popular with the grower because of its high yield of grain, and with the miller because of its high yield of flour of good color and quality.

There are three factors which make it desirable that Ohio farmers continue to grow winter wheat of the soft red type. These are climate, market demands, and yield of grain. We believe it would be a serious mistake for Ohio farmers to attempt to grow a red winter wheat of the hard type carrying a high percentage of protein comparable to that grown in the southern portion of the Great Plains area, in view of our climatic limitations, market demands, and the lower yield of the high-protein types.

That neighboring states are taking somewhat the same attitude toward the problem is evident. Michigan is pushing its Red Rock variety; Pennsylvania, its Penn. 44; New York, its Forward; Kentucky, its Ashland; and Indiana, its Purkoff.

Quality in wheat may be defined for our purpose as "the specific physical and chemical structure which will best enable the wheat to meet its consumption demands." This will vary with the several uses to which the wheat may be put, such as flour for bread, pastry, macaroni, general household use, cereal foods, etc.

Plumpness of kernel and test weight per bushel are the main indices by which the quality of soft red winter wheat is ordinarily judged. A high correlation exists between these indices and flour yield. For the soft red winter section of the United States, the quality of the gluten is more important than the amount.

In reporting the work of the Ohio Experiment Station, therefore, test weight per bushel will be given a prominent place. Schollenberger (13) has shown that 62-pound soft red winter wheat yielded approximately 72% flour and 54-pound wheat 66% flour. This represents a decrease of 1% in flour yield for every 1½ pounds decrease in test weight. In other investigations, Schollenberger found that the higher the test weight, the larger was the proportional amount of higher grade flour produced. The color and texture of the bread was found to decrease uniformly as the test weight decreased. He also found that the protein content, on the average, increased with a decrease in test weight. This is contrary to the findings of Bailey and Hendel (4) and of Mangels and Sanderson (9), who found little or no correlation between weight per bushel and protein content of flour.

Correlations have been determined between the test weight per bushel and protein content of grain for the crop years of 1912 and 1925, using the wheat from several of the plats in the five-year rotation fertility test at Wooster. In 1912 a significant negative correlation was secured of — 0.863 ± 0.049, whereas for 1925, a small positive correlation of + 0.246 ± 0.057 was obtained. Evidently, heavy or light testing wheat may have either a high or low protein content.

Ames, Boltz, and Stenius (1), and Ames and Boltz (2), working with wheat from these same plats, showed the pronounced effect of the different treatments upon the physical development of the kernels. Wheat from the unfertilized check plats had the largest percentage of shriveled kernels. The addition of nitrogen to the soil tended to increase the amount of shriveled kernels, whereas the addition of phosphorus tended toward the production of plump kernels. An abundance of nitrogen and a deficiency of phosphorus produced high protein wheat. Potassium tended to increase plumpness to a slight extent.

No attempt will be made to review in detail the rather extensive literature dealing with modifications of the composition of the wheat kernel as the result of varying the moisture and food supply. Bailey (5) has fully covered the literature on the subject. I shall only refer to certain of the experimental results of others which seem to have a bearing upon the Ohio results here reported.

THE OHIO EXPERIMENTS

EFFECT OF APPLYING SODIUM NITRATE AT INTERVALS TO DAWSON'S GOLDEN CHAFF WHEAT[4]

In the spring and early summer of 1922, a field test was conducted by R. H. Simon and the author in which certain winter wheat plats were topdressed with sodium nitrate at intervals throughout the growing season. Thirty-three square-rod plats of a pure-line selection of Dawson's Golden Chaff wheat were treated at intervals at the rate of 200 pounds per acre, in some cases the application being made all at one time and in others at different times. The treatments were in triplicate, making 11 different treatments. In addition, six plats were left without treatment to serve as checks. The wheat was seeded at the rate of 8 pecks per acre.

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[4] The chemical analyses reported in this paper were made by R. H. Simon under the direction of J. W. Ames, and the milling and baking records by Miss M. K. Corbould of the Agronomy Department. The author wished to express his appreciation for the service rendered.

The object sought was the effect of the nitrate upon the yield and tillering of the plants and on the nitrogen content of the straw and protein content of the grain. The soil was the native Wooster silt loam, which had been limed at intervals during the past 15 or 20 years and was in a fairly high state of productivity. Four hundred pounds per acre of a home-mixed fertilizer analyzing 0–14–3 was applied to the seedbed at the time of sowing the wheat in the fall.

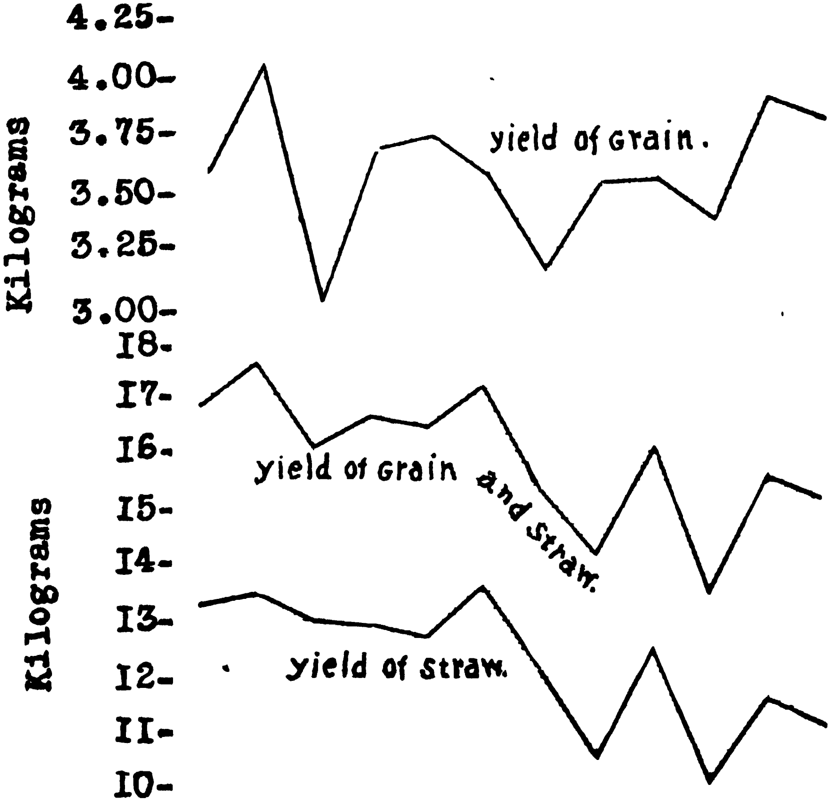

FIG. 1.—Wheat treated with nitrate of soda at intervals.

The application of sodium nitrate was begun on March 15 and continued at 30- or 31-day intervals up to and including June 15. The amounts and times of application were as follows:

200 pounds at one application on each of four series: March 15, April 15, May 15, and June 15.

200 pounds in two applications of 100 pounds each on six series:

March 15	March 15	March 15	April 15	April 15	May 15
April 15	May 15	June 15	May 15	June 15	June 15

200 pounds in four applications of 50 pounds each on one series: March 15, April 15, May 15, and June 15.

Briefly, the results which may be of interest at this time are as follows:

1. The early applications gave an increased total yield of grain and straw (Fig. 1). The tendency was more pronounced in the straw yield, the grain yield not showing any significant difference between early and late applications. The ratio of grain to straw in-

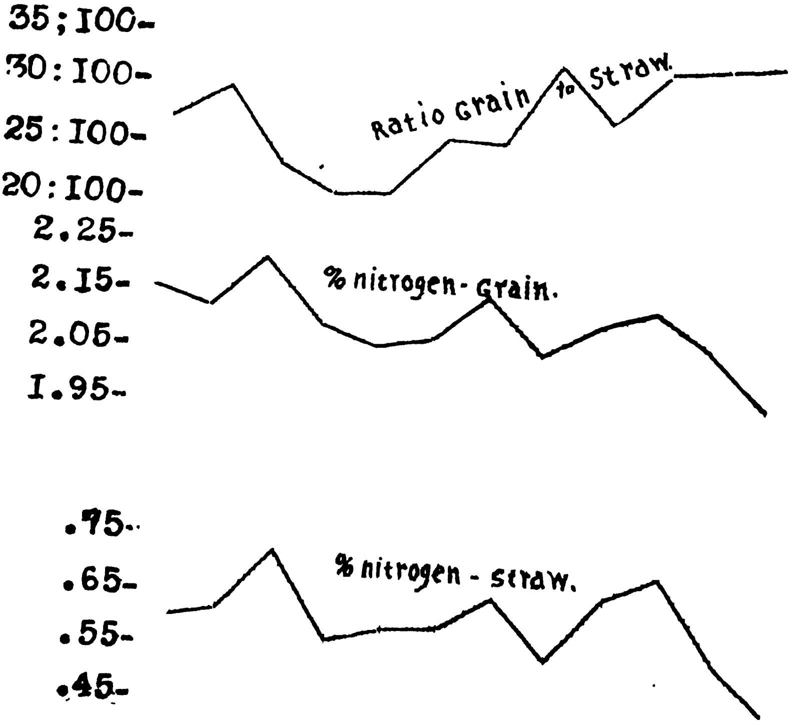

FIG. 2.—Wheat treated with nitrate of soda at intervals.

creased as the applications of nitrate were made later in the season (Fig. 2). The early applications also increased the tillering of the plants.

2. There was a slight tendency for the percentage of nitrogen in the grain to decrease with the later applications of nitrate. The check plats which receive no nitrate had the lowest nitrogen content. The highest protein content of grain, 11.97% (N X 5.7), was from the plat which received nitrate at the rate of 100 pounds on March 15 and again on April 15, and the lowest, 10.63%, was from the check plats which received no nitrate The difference of 1.34% protein is very small indeed and may not be significant.

3. The nitrogen removal per plat was greatest for the early applications of nitrate (Fig. 3), this being a corollary of the higher total yield and slightly higher nitrogen content of the crop.

Summarizing the results of this test, it will be found that the chief effect of the application of sodium nitrate at intervals throughout the growing period was to increase the straw yield with the early applications. No marked effect was noted on the percentage of

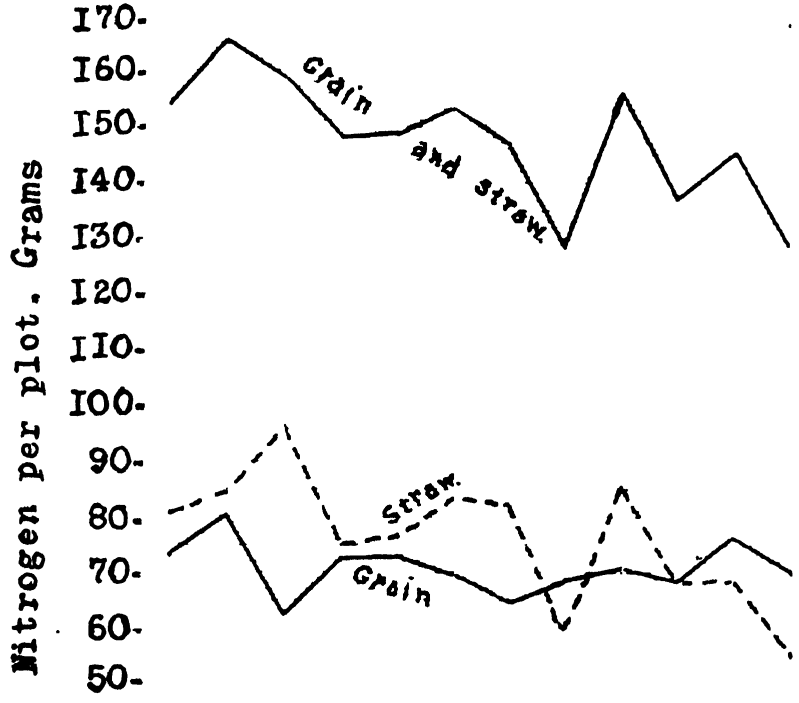

FIG. 3.—Wheat treated with nitrate of soda at intervals.

nitrogen in the crop. Milling and baking tests of the grain and flour showed no appreciable effect on flour yield or loaf volume for any applications. There was a negative correlation of — 0.484 ± 0.143 between the percentage of nitrogen in grain and the weight of 100 kernels.

It goes without saying that this test should be repeated before any great credence be given to the results.

The negative evidence is worth something, however, in showing that the time of application of sodium nitrate is not in itself the only factor involved. The specific condition under which the late applications of nitrates modify protein content of the grain under field conditions needs to be better understood.

It should be borne in mind that soil moisture was at no time a limiting factor in this test and that an abundant supply of phosphorus and potassium were present. No determinations of nitrates in the untreated soil were made. It is probable, however, that sufficient available nitrogen was present for normal development, the protein content of 10.63% for the check plats certainly not indicating nitrogen starvation. Additional nitrates increased yield much more than protein content.

It is of interest to note that Neidig and Snyder (10) say that, "When the available nitrogen is sufficient for a maximum growth of plant, both yield and protein will be influenced, but yield more than protein. It is noted that the wheat plant carefully regulates the protein content and if there is a lack of available nitrogen or moisture, yield is the first to be decreased."

It is of interest to note that Davidson (7), had somewhat similar results with a soft red winter wheat in Maryland. Nitrates applied at different times in the spring increased the yield with the earlier applications. The protein content was in inverse ratio to the yield.

Olsen (12) concludes that, "The protein of wheat depends, first, upon the supply of available nitrogen for the plant and, second, upon the movement of nitrogenous material into the grain," and "that larger quantities of water are required to move the nitrogenous matter than the non-nitrogenous matter into the kernels. Accordingly, water should prove to be beneficial to high rather than to low nitrogen content."

These conclusions of Olsen seem to be at variance with the larger part of the experimental evidence, especially those with the use of irrigation water, which seem to show that the protein content decreases with the increased application of irrigation water within practical limits. It seems probable that studies in transpiration rate as well as moisture supply might help to explain some of the seemingly contradictory results.

EFFECT OF TEST WEIGHT PER BUSHEL OF SEVERAL FERTILIZER TREATMENTS APPLIED TO FIVE-YEAR ROTATION FERTILITY PLATS AT WOOSTER

Test weight per bushel determinations have been made of the wheat grown on limed and unlimed ends of the several plats in the five-year rotation fertility test at Wooster. Some of these, together with certain chemical determinations and milling and baking records, are presented in this paper in an attempt to show the effect of various fertilizer applications upon the quality of the wheat. A complete discussion (Thorne, 14) of the effect of the several treatments upon yield, covering the 30-year period from 1894 to 1923, is given in Ohio Experiment Station Bulletin 381. No attempt will be made at this time to discuss in detail the results reported therein.

The soil under investigation is the Wooster silt loam, easily worked and well drained. Being naturally somewhat deficient in phosphorus and lime, it quickly responds to applications of these, especially after a period of crop removal without adequate return of the elements removed. The Wooster silt loam soil is well adapted to wheat growing and the counties of Ohio lying within this soil type have a reputation for producing wheat of excellent quality.

The five-year rotation fertility test consists of 150 one-tenth acre plats, 30 each of corn, oats, wheat, clover, and timothy in the order named, a crop of each being grown every year. Twenty of these plats receive some treatment either as chemical fertilizers or manure. Ten check plats systematically distributed throughout each series receive no treatment with fertilizer or manure. In addition to the fertilizer and manure treatments, all plats have been cross dressed with lime on the west end, beginning with 1900, as the plats were being prepared for corn. Certain of the sections, E, B, and A also received a dressing of lime on the east end in 1905, 1906, and 1907, respectively, but none on the east end since that time. In harvesting the crops, the limed and unlimed ends are kept separate. In this report "limed ends" will refer to west ends and "unlimed ends" to east ends of all sections regardless of the one application made on the east end of the three sections in 1905, 1906, and 1907. The plan of the experiment was as follows:

Plat No.	Fertilizer treatment per rotation in pounds per acre
2	Acid phosphate, 320 pounds.
3	Potassium chloride, 260 pounds.
5	Sodium nitrate, 480 pounds.

6	Acid phosphate, 320 pounds; sodium nitrate, 480 pounds.
8	Acid phosphate, 320 pounds; potassium chloride, 260 pounds.
9	Potassium chloride, 260 pounds; sodium nitrate, 480 pounds.
11	Acid phosphate, 320 pounds; potassium chloride, 260 pounds; sodium nitrate, 480 pounds.
17	Acid phosphate, 480 pounds; potassium chloride, 260 pounds; sodium nitrate, 240 pounds.
18	Yard manure, 16 tons (8 on corn, 8 on wheat).
24	Fertilized as 17, but nitrogen in ammonium sulfate.
26	Fertilized as 11, but phosphate in bone meal.
29	Fertilized as 11, but phosphate in basic slag.
Check (10 plats)	No treatment.

In reporting the effect of these treatments on the quality of the wheat crop, the crop years from 1914 to 1925, inclusive, are used with the exception of 1915 and 1919 for which years the test weights per bushel records are incomplete. Student's method, showing the relative significance of the differences between the 10-year test weights of wheat grown on plats receiving the treatments indicated. The odds in favor of any treatment represented by a column over a line are found at the intersection of the column and line. For example, the odds are 267 to 1 that plat No. 8, receiving phosphoric acid and potash, has a heavier test weight than plat No. 5 which receives nitrogen alone. It will be noticed that the test weights per bushel for the check plats receiving no treatment and for plat No. 5 receiving nitrogen alone have been the lowest. When the check plats and nitrogen plat (No. 5) are compared directly, the odds are even. When the odds for any treatment over the check (found in the nine entries to the right of checks in the table) are compared with any treatment over plat No. 5, it is noted that the odds are larger for the treatment over the check in every case except for plat No. 2. This is a suggestion that the test weight per bushel of plat No. 5 is consistently heavier than the check plats. The average test weight for the checks is 58.351 pounds and for plat No. 5 it is 58.397. Evidently the difference is practically negligible.

Of the single element plats, that of nitrogen (No. 5) has the lowest test weight followed by potassium (No. 3) and phosphorus (No. 2). The odds are 382 to 1 that the phosphorus wheat (No. 2) is heavier than the nitrogen wheat (No. 5), the actual difference in weight between the two lots of wheat being 1.223 pounds per bushel. When nitrogen is added to phosphorus (No. 6) or to potassium (No. 9), the test weight is lowered, although the odds are only 10 and 11 to 1 in favor of phosphorus alone.

The combination of phosphorus and potash (No. 8) gives a heavier test weight than any single or double element and is but slightly less than the complete fertilizer plats (Nos. 11 and 17) and the manure plat (No. 18). Direct comparison of plats Nos. 11 and 17 show that the odds are even. When compared with other treatments, however, it will be noted that, in every case, increasing the phosphorus and decreasing the nitrogen on plat No. 17, as compared with plat No. 11, has given odds in favor of plat No. 11. This may be accounted for, in part, by the fact that plat No. 11 has given higher test weights on the limed ends than has plat No. 17.

TABLE I.—*Showing the relative significance of the difference between the 10-year average test weights of wheat on the five-year rotation plats at Wooster.*[a]

		Plat No. 2 P	3 K	5 N	6 P N	8 P K	9 K N	11 P K N	17 2P K ½N	18 M
Ch.	O	352	1227	1	102	976	4	7532	734	652
2	P					4		48	19	18
3	K	8				13		78	65	83
5	N	382	1021		85	267	2	1071	585	409
6	P N	10	3			45		515	286	160
8	P K							5	3	4
9	K N	11	9		6	139		158	54	57
11	P K 2N								1	1
17	2P K N									1

[a] The odds in favor of any treatment represented by a column, over any line, is found at the intersection of the column and line.

It will be noted also that adding nitrogen to both phosphorus and potassium has resulted in increasing the test weight, whereas when nitrogen was added to either phosphorus or potassium alone the test weight was lowered. The effect of available nitrogen in the soil upon test weight seems to depend somewhat upon the relative amounts of available phosphorus and potassium in the soil.

If these are present in sufficient amounts to support normal growth, additional nitrogen increases vegetative growth and yield. If not sufficient, then the plant indulges in a luxury consumption of nitrogen, disturbing the nitrogen-carbohydrate ratio and producing a plant high in protein and usually with a decreased yield of grain when compared with plants receiving a more nearly balanced supply of phosphorus and potassium. If, on the other hand, phosphorus, potassium, and moisture are sufficient to support a maximum crop and more than enough nitrogen to balance them be added, an overproduction of vegetative tissue results, sometimes accompanied by lodging. Excessive self shading by the plants reduces photosynthesis and a high-nitrogen, low-carbohydrate product results.

Before going on with the five-year rotation fertility test results, attention is called to some results that have been secured in a fertility test started in 1915. This is a four-year rotation of corn, oats, wheat, and clover in which 1,000 pounds of fertilizer per rotation are used. Table 2 gives the average test weight for wheat grown on a few of the plats.

The average test weight for seven check plats (Nos. 1, 4, 7, 10, 13, 16, and 19) is used for comparison with the treated plats growing beside them. All plats, including the checks, receive a basic treatment of lime as the seedbed is being prepared for corn.

TABLE 2.—*Showing the odds that fertilized plats have higher test weight than check plats (lime only).*

8-year average, Fry farm, four-year fertility plats, Wooster, Ohio.

Plat No.	Fertilizer treatment per rotation, 1,000 pound per acre	Odds
2[a]	0–16–0	174 to 1
3[a]	0–12–4	61 to 1
5[a]	2– 8–2	50 to 1
8	2– 8–2	129 to 1
14	2–12–2	357 to 1
15	4–12–2	187 to 1
17	4– 8–4	49 to 1
18	4– 8–8	179 to 1

[a] 250 pounds on each crop; all others 500 pounds on corn, 500 pounds on wheat.

Plats Nos. 2, 3, and 5 each receive 1,000 pounds of fertilizer in the four-year rotation, 250 pounds each year. The other plats shown in the table receive 500 pounds on the corn and 500 pounds on the wheat.

A study of this table supports the conclusions deduced from the five-year rotation fertility test. Here, again, phosphorus increased the test weight and potassium to a lesser degree, whereas nitrogen has had the opposite effect. The heaviest wheat has been produced on plat No. 14 receiving the 2–12–2 fertilizer mixture. It is an interesting coincident that this treatment has also been the most profitable in the series.

INFLUENCE OF LIME ON TEST WEIGHT PER BUSHEL

The application of lime to the west ends of the five ranges in the five-year rotation fertility test has had a pronounced effect upon the yield of crops.

In Table 3 is shown the effect of lime upon the 10-year average test weight per bushel of wheat grown on 12 of the treated plats and on the check plats. The odds for any single plat are rather small, the odds for 11 of them being in favor of the east (unlimed) end and two for the west (limed) end. The odds can hardly be considered significant. The largest odds are for plat No. 26 which is fertilized the same as plat No. 11 but which gets its phosphorus in bone meal.

TABLE 3.—*Showing the effect of lime on the 10-year average test weight per bushel in the five-year rotation fertility plats, Wooster, Ohio.*

Plat No.	Average test weight in pounds		Odds in favor of east end
	East	West	(Student's method)
2	59.81	59.42	3 to 1
3	59.58	59.17	4 to 1
5	58.80	57.99	7 to 1
6	59.56	58.89	5 to 1
11	60.20	60.09	1 to 1
17	60.42	59.93	10 to 1
18	60.22	60.22	1 to 1
24	60.46	59.73	5 to 1
26	60.56	59.15	32 to 1
29	59.99	59.95	1 to 1
All checks	58.56	58.14	4 to 1
	West	East	Odds in favor of west end
8	60.32	59.59	7 to 1
9	58.73	58.57	1 to 1

TABLE 4.—*Showing the odds of test weight per bushel in the five-year rotation fertility plats at Wooster in a comparison of the limed ends (west) with no lime (east).*

	Average of 10 check plats				Average of 10 fertilized plats			
Year	East	West	d	Odds in favor of East	East	West	d	Odds in favor of East
1925	60.810	58.445	2.365	9999 to 1	60.475	58.845	1.630	9999 to 1
1924	57.885	54.415	3.470	9999 to 1	59.835	57.670	2.165	9999 to 1
1923	58.950	58.050	0.900	110 to 1	——	——	——	——
1921	55.025	52.825	2.200	1428 to 1	58.275	56.500	1.775	160 to 1
1922	——	——	——	——	59.775	59.770	.750	1 to 1
	West	East	d	Odds in favor of West	West	East	d	Odds in favor of West
1922	58.375	57.850	0.525	262 to 1	——	——	——	——
1920	54.250	53.825	0.425	50 to 1	——	——	——	——
1918	61.950	59.300	2.650	4999 to 1	62.875	60.925	1.950	9999 to 1
1917	60.635	60.400	0.235	21 to 1	——	——	——	——
1916	60.560	60.175	0.375	262 to 1	60.850	60.500	.350	11 to 1
1914	61.950	61.400	0.550	30 to 1	——	——	——	——

There seems to be little evidence that liming the land has affected the test weight per bushel *as a 10-year average.* When the data are analyzed on the basis of annual results, however, it is found that liming the land has been accompanied, in certain years, by a pronounced effect upon the test weight. Taking up Table 4, we have a comparison of the limed and unlimed ends in one case of 10 check plats and in another of 10 fertilized plats. The seasons of 1924 and 1925 produced wheat which was much heavier on the east (unlimed) ends for both the check plats and the fertilized plats. On the other hand, the crop of 1918 was much heavier on the west (limed) ends for both the check plats and the fertilized plats. Lime does not seem to have had a marked effect during the other seasons, with the possible exception of 1921.

In casting about for some explanation of the seasonal effect of 1918, 1924, and 1925, it was thought that possibly the straw-grain ratio might shed some light on the problem. With this in mind, a correlation table was prepared between test weight per bushel and pounds of straw per bushel of grain. The correlations are shown in Table 5.

TABLE 5.—*Correlation between test weight per bushel and pounds of straw per bushel of grain in five-year rotation fertility plats at Wooster.*

12 fertility and 10 check plats, east and west ends.

Year	Coefficient of correlation
1918	—.5079±.0981
1924	—.6412±.0778
1925	—.6256±.0804
10-year average	—.3900±.0510
10-year average, Checks only	—.3772±.1294

A very significant negative correlation was secured for the years 1918, 1924, and 1925. The correlation for the 10-year period, although smaller, is still significant when compared with its probable error. It may be concluded, therefore, that a decrease in test weight per bushel would accompany an increase in the straw-grain ratio. If that be true, then a table of odds of the straw to grain ratio should be the reverse of the test weight table for the limed and unlimed ends. Such was the case for the three years in question as indicated in Table 6.

The negative relationship is quite pronounced in the years 1918 and 1925, less so for 1924 and 1921.

An examination of the actual yields of grain and straw for 1918 and 1925, the two years of opposite reaction, show a smaller grain yield in 1918. However, we find that in 1918, the unlimed end (east) of the fertilized plats yielded more than the unlimed (east) ends in 1915, and the limed (west) end in 1918 less than the corresponding end in 1925. The limed ends (west)for the same plats in 1918 were only 4.11 bushels more than the unlimed, whereas, in 1925 the limed ends were 12.83 bushels larger. The unfertilized check plats follow the same trend. The actual yield of straw in 1918 was greater than in 1925.

TABLE 6.—*Showing the odds of pounds of straw per bushel of grain in five-year rotation fertility plats at Wooster, comparing limed ends (west) with no lime (east).*

	Average 10 check plats				Average 10 fertilized plats			
Year	West	East	d	Odds in favor of West	West	East	d	Odds in favor of West
1925	70.2	59.6	10.6	4999 to 1	81.3	65.9	15.4	1413 to 1
1924	137.5	119.2	18.3	301 to 1	127.4	116.4	11.0	76 to 1
1923	87.1	75.0	12.1	42 to 1	—	—	—	—
1921	128.9	110.2	18.7	633 to 1	—	—	—	—
1914	99.1	97.7	1.4	1.4 to 1	—	—	—	—
1916	—	—	—	—	100.2	95.2	5.0	197 to 1
	East	West	d	Odds in favor of East	East	West	d	Odds in favor of East
1921	—	—	—	—	117.1	108.3	8.8	8 to 1
1922	115.7	108.3	7.4	13 to 1	108.9	100.8	8.1	17 to 1
1920	133.9	97.4	36.5	8 to 1	—	—	—	—
1918	105.0	90.5	14.5	4999 to 1	102.7	92.3	10.4	193 to 1
1917	85.9	85.1	.8	2 to 1	—	—	—	—
1916	102.3	100.6	1.7	2 to 1	—	—	—	—

An examination of the meteorological data for the two years discloses a marked difference in the precipitation for the month of May. The precipitation for February, March, and April was fairly comparable, being in both years, a little below the 37-year average. May, 1918, had 4.88 inches of rainfall and May, 1925, 1.87 inches; the 37-year average being 3.98 inches. June, 1918, and June, 1925, were both below the average of 4.05 inches, being 1.91 inches and 2.35 inches, respectively. The temperature for May, 1918, was 6.8 degrees above normal and for 1925, 4.6 degrees below normal. We had, then, a wet, warm May in 1918 and a cool, dry May in 1925, otherwise the weather was about the same throughout the crop season. Just why this should be more favorable to a high test weight of grain on limed land in one case and on unlimed land in another is not quite clear.

MILLING AND BAKING RECORDS, TOGETHER WITH PROTEIN AND ASH DETERMINATIONS ON THE WHEAT

Table 7, gives the protein and ash in the 1925 crop for the plats under discussion. Through an oversight, the sample from the potassium and nitrogen plat (No. 9) was not included in the chemical analyses and milling and baking tests.

TABLE 7.—*Percentage protein and ash in wheat, 1925 crop, east and west halves of five-year rotation fertility plats at Wooster.*

Plat No.	Treatment	Protein (N X 5.7)		Ash	
		East	West	East	West
2	P	9.92	9.67	1.567	1.715
3	K	10.90	11.57	1.417	1.520
5	N	11.19	11.57	1.390	1.745
6	P, N	10.37	10.74	1.830	1.492
8	P, K	10.08	10.08	1.537	1.585
11	P, K, N	10.74	10.74	1.498	1.655
13	Nothing	9.92	10.57	1.700	1.717
17	2 P, K, ½N	9.67	10.49	1.552	1.687
18	16 tons manure	10.49	10.90	1.587	1.682
24[a]	N in ammonium sulfate	10.08	11.40	1.492	1.577
26[b]	P in bone meal	9.67	11.57	1.437	1.705
29[b]	P in basic slag	9.67	10.90	1.515	1.492

[a] Fertilized as No. 17.
[b] Fertilized as No. 11.

Taking up the protein first, it will be noted that the limed end (west) has produced a higher average protein wheat than the unlimed (east). The protein in the wheat is higher on the limed end for every plat except plats Nos. 8 and 11 in which case the protein is the same on both ends. On the unlimed end (east) we find the highest protein content in the wheat from the plat receiving sodium nitrate alone (No. 5). It is one of the highest on the west end also. On the unlimed end we find the least protein on the phosphorus plat (No. 2) and on the check plat (no treatment). Liming the check plat on the west end increased the protein content much more than liming the phosphorus plat. The addition of phosphorus to nitrogen decreased the protein content on both ends. A similar result was secured by adding phosphorus to potash. Supplying the nitrogen as ammonium sulfate on plat No. 24 increased the protein content of the wheat on both east and west ends over plat No. 17 which gets its nitrogen as sodium nitrate.

Considering next the ash, we find that the wheat on the limed ends (west) has a higher ash content than that on the unlimed ends (east), the odds by Student's method being 18.3 to 1 in favor of the limed ends. It is evident that some slight correlation exists between the effect of liming the land, the protein and ash content, and the test weight per bushel. This is in agreement with the conclusions of Newton and Malloch (11), who find the ash content an index of flour yield, being inversely proportional to plumpness and high test weight per bushel.

Ames and Schollenberger (3) found decidedly more phosphorus in the 1910 crop of wheat grown on the east (unlimed) end of Sec. C of this test, the odds being by Student's method 2000 to 1 that the grain from the limed fertilized plats averaged as much as 0.01% higher in phosphorus.

Table 8, shows the protein content of wheat, the flour yield, and the loaf volume. Since the protein relations have been discussed, nothing more need be said about them here. The flour yields seem to have been little affected by the several treatments. It might be noted that the lowest flour yield was secured from the unfertilized wheat (check plat No. 13.)

TABLE 8.—*Milling and baking record, 1925, five-year rotation fertility plats at Wooster.*

Plat No.	Treatment	Protein in wheat		Flour yield		Loaf volume	
		East	West	East	West	East	West
		%	%	%	%	cc.	cc.
13	Check, none	9.92	10.57	66.0	66.0	2,050	2,150
2	P	9.92	9.67	66.8	67.9	2,225	2,100
3	K	10.90	11.57	66.7	66.1	2,115	2,125
5	N	11.19	11.57	67.0	66.0	2,050	2,160
6	P, N	10.37	10.74	68.4	65.8	2,090	2,100
8	P, K	10.08	10.08	67.1	67.5	2,190	2,100
9	K, N	No sample saved					
11	P, K, N	10.74	10.74	68.8	69.7	2,225	2,100
17	2P, K, ½N	9.67	10.49	69.0	64.0	2,150	2,100
18	Manure	10.49	10.90	67.5	70.0	2,250	2,025
24	Ammonium sulfate	10.08	11.40	65.2	67.7	2,225	2,175
26	Bone meal	9.67	11.57	68.4	65.0	2,275	2,185
29	Basic slag	9.67	10.90	66.7	68.5	2,200	2,050
Average		10.225	10.850	67.3	67.0	2,170	2,114

The loaf volume is larger on the unlimed ends (east) for all the complete fertilizer plats, manure, and for plat No. 2, phosphorus alone, and plat No. 8, phosphorus and potassium. Lime seems to have increased the loaf volume on the check plat (No. 13), on the single element plats potassium (No. 3) and nitrogen (No. 5), and on the double element plat phosphorus and nitrogen (No. 6). These differences, however, are small.

A correlation of — .350 ± .120 has been found between ash content of wheat and loaf volume and + .231 ± .094 between protein content and loaf volume.

SUMMARY

In 1912, a very significant negative correlation between test weight per bushel and protein content of — .863 ±.049 was determined for wheat on several differently treated plats in the five-year rotation fertility test at Wooster. In 1925, the correlation was +.246 ± .057.

The addition of nitrogen increased the percentage of shriveled kernels. Phosphorus markedly increased plumpness, and potassium to a less degree.

The application of sodium nitrate to Dawson's Golden Chaff wheat at 30- and 31-day intervals from March 15 to June 15 increased the yield of straw and the number of tillers per plat as the applications were made earlier in the season. The grain-to-straw ratio decreased as the applications were made later. Very little effect was noted on protein content of grain. The total nitrogen removal per plat in the crop was greatest for the early applications of nitrate.

In the five-year rotation fertility test at Wooster, the 10-year average test weight per bushel of wheat was the lowest on plats receiving no fertilizer treatment or manure and on the plats receiving sodium nitrate alone. Phosphorus alone and potassium alone gave consistently heavier wheat than nitrogen alone. When nitrogen was added to either phosphorus or potassium, the test weight was lowered; when added to both phosphorus and potassium, it was raised.

In the Fry farm four-year rotation fertility test, in which 1,000 pounds of fertilizer are applied per rotation, increasing the phosphorus in the fertilizer increased the test weight and increasing the nitrogen lowered it.

On the average of 10 years, liming the west half of the fertility plats in the five-year rotation has had little effect upon the test weight per bushel. In 1918, however, heavier wheat and less straw per bushel of grain were produced on the limed ends, and in 1924 and 1925 on the unlimed ends.

The correlations between test weight per bushel of grain and pounds of straw per bushel of grain are — .5079 ± .0981 for 1918, — .6412 ± .0778 for 1924, and — .6256 ± .0804 for 1925. A small negative correlation was secured for the 10-year average.

A warm, wet May in 1918 gave a comparative high straw-to-grain ratio and low yield of grain; in 1925 a comparatively cool, dry May resulted in a low straw-to-grain ratio and high yield of grain. The fact seems established that the effect of liming the land upon test weight and straw-to-grain ratio is correlated with seasonal conditions. No explanation is offered for the correlation.

The wheat from the limed ends of the 1925 crop contained, on the average, more protein than the unlimed ends, although the difference was small.

The use of sodium nitrate alone produced the highest percentage of protein in the wheat of any treatment on both limed and unlimed ends, and phosphate alone gave the lowest percentage of protein on the west end and tied with the check plats on the east. The addition of phosphorus to nitrogen and to potassium decreased the protein content on both ends. Nitrogen supplied as ammonium sulfate increased the protein content more than an equal amount of nitrogen in sodium nitrate.

The wheat on the limed ends contained slightly more ash than that on the unlimed ends. A slight negative correlation of — .350 ± .120 was found between ash content and loaf volume.

The flour yield from all plats was practically the same, the lowest yield being secured from the check plat.

Loaf volume bears little relation to the protein content, a correlation of + .231 ± .094 being found for all plats.

In general, the wheat from the unlimed ends of the complete fertilizer, manure, phosphorus alone, and phosphorus with potassium plats gave larger loaf volumes than the limed ends. Lime increased the loaf volume on the check plat, nitrogen alone, and potassium alone and in combination.

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4. BREEDING WHEAT FOR HIGH PROTEIN CONTENT[1]

J. ALLEN CLARK[2]

INTRODUCTION

Methods of controlling the quality of crops through the use of rotations, fertilizers, and legumes, and by proper dates of seeding and harvesting are becoming known. It is important to determine and apply methods of controlling the quality of crop products through environment, but the make-up of the plants themselves also must be considered. By improvement in the inherent characteristics of crop varieties so that we secure a significant increase in yield and quality for each environment evolutionary progress is made, and only when a maximum for each environment results complete success will have been attained.

Marked improvement in production through the use of better varieties frequently occurs. There are also significant differences in the quality of varieties. With wheat, one need go no further than the Marquis variety for an outstanding example of improvement in both quality and production. While engaged in the important problems of maintaining and improving the quality of crop products by cultural and other practices, therefore, we should also concern ourselves with improving the inherent quality of the crop itself.

The term quality is relative and involves many factors. In milling and baking experiments with wheat conducted by the United States Department of Agriculture 20 characteristics are studied. Each of these and probably several more are important quality factors. There is no one determination to be applied to wheat or flour which will accurately reveal its quality. Of all those used to indicate the milling and baking value of wheats, the crude protein content is probably the most reliable. Crude protein content is also economically more important than any other single factor. While recognized as not an infallible measure of quality, crude protein content at the present time over-shadows grade in establishing price and is the determining factor within a particular grade. For wheats of equal grade, premiums of from 3 to 15 cents per bushel are paid in most years for each increase of 1% in crude protein above 11%. The premiums vary with the quality of the crop each year and the quality of high protein wheat available. In general, an improvement of 1% in crude protein content adds 10 cents per bushel to the value of the crop.

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INHERITANCE OF CRUDE PROTEIN CONTENT

In connection with problems of breeding for production the writer also has recognized the necessity for and has attempted to study quality. All quality factors could not be considered in a breeding program because of the expense and the limited amount of grain produced from individual plants in the early generations. The crude protein content may be determined with a high degree of accuracy from a small quantity of grain. Recognizing its value and limitations this measure of quality was chosen for study in certain crosses. From such studies it is hoped to determine the mode of inheritance of this important economic quality factor and to develop a superior quality product. It is felt that some of the early results should prove of interest at this time.

SEGREGATION OF PROTEIN CONTENT

In an attempt to determine the segregation and inheritance of crude protein content in hybrids, studies were started with certain crosses grown in Montana under environmental conditions favorable for high protein content, and in California under conditions usually producing wheat low in protein.

STUDIES OF MARQUIS-HARD FEDERATION CROSSES GROWN IN MONTANA

The grain from individual plants in an F_2 population of Marquis x Hard Federation wheats and of the parent varieties grown at Bozeman, Mont., in 1923, was analyzed for crude protein content.[3] The crop was spring sown on summer-fallowed land under conditions favorable for the development of wheat of high protein content. The plants were grown in rod rows 1 foot apart from seed spaced 3 inches apart in the row. The plants were harvested and threshed and the yield recorded for each separately. A 2-gram sample of the grain from each plant was used for the crude protein determinations. The kernels of both of the parent varieties were hard and there was no apparent segregation for texture. The data obtained are shown in Fig. 1.

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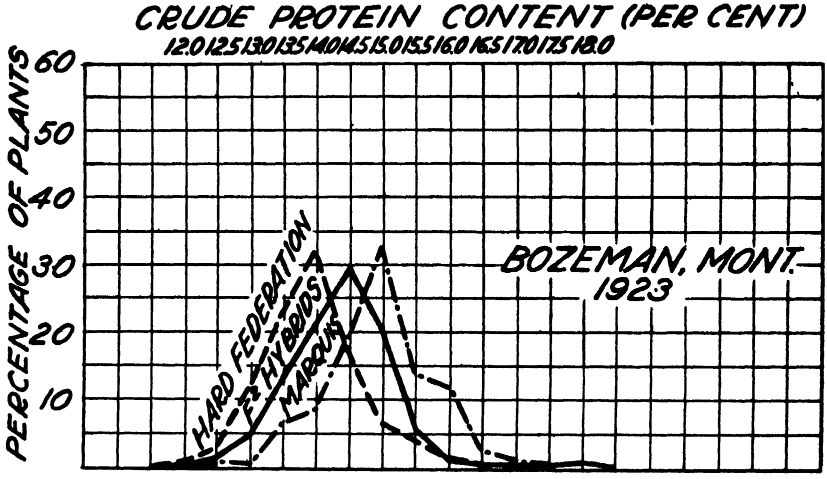
[3] The crude protein determinations were made in the Research Laboratory of the Grain Division of the Bureau of Agricultural Economics, U. S. Department of Agriculture, under the direction of Dr. D. A. Coleman.

The data show that in the F_2 the hybrids were intermediate with respect to the parents in crude protein content. Marquis exceeded Hard Federation in average content by 0.95 ± 0.08%, a significant difference. The average protein content of the hybrids differed from that of Hard Federation by 0.38 ± 0.05%, and from that of Marquis by 0.57 ± 0.06%, both differences being significant. The hybrids were nearer the parent of lower average content. Coefficients of variability show that the F_2 hybrids were not significantly more variable in crude protein than was either parent.



HYBRIDS & PARENTS	NUMBER OF PLANTS	TOTAL	MEAN AND P.E.
F² HYBRIDS	1 8 27 74 121 168 118 38 8 2 1 1	567	14.37±.02
HARD FED.	2 11 21 31 17 5 4 2	93	13.99±.05
MARQUIS	1 1 6 8 19 31 14 12 3 1	96	14.94±.06

FIG. 1.—Segregation in the F_2 generation into frequency classes for crude protein content of the grain of F_2 plants of Marquis-Hard Federation crosses in comparison with that of the parent varieties, grown at Bozeman, Mont., in 1923.

The average yields of the hybrid plants significantly exceeded those of both parents. The crude protein content of the hybrid plants was negatively correlated with yield, the coefficient of correlation being — 0.231 ± 0.027. The data are shown in Table 1. Yield affected the protein content of the hybrids more than any other one of the factors studied, which included dates of heading and ripening, fruiting period, and height. The negative correlation is not large but it is significant, being more than eight times its error.

TABLE 1.—*Correlation between crude protein content and yield of F_2 plants of Marquis-Hard Federation crosses grown at Bozeman, Mont., in 1923.*

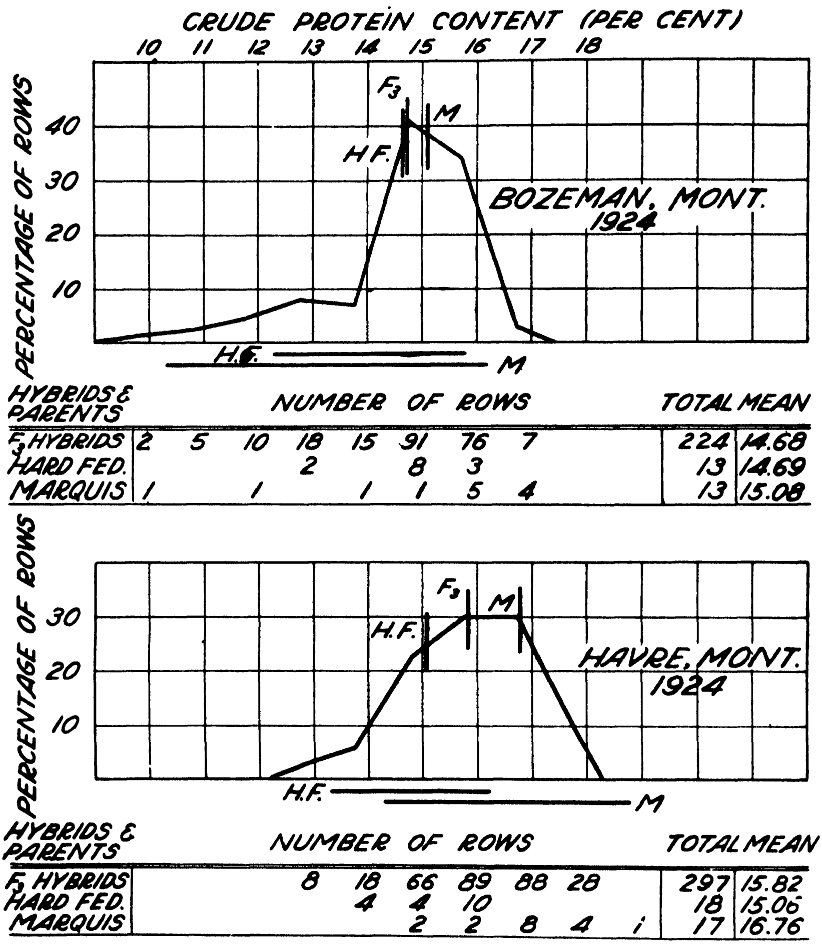
Yield of	Crude protein content of F_2 plants													Totals
F_2 plants	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	
2.5					2	2	1	1	1	1				8
3.5		2		1	3	10	12	4	1					33
4.5		1		4	9	14	19	4	2					53
5.5			3	14	19	30	22	10	2					100
6.5		1	10	12	32	44	27	8	1		1			136
7.5	1	2	6	14	22	34	20	6	1				1	107
8.5		1	4	11	16	18	13	1		1				65
9.5			4	11	15	9	2	3						44
10.5		1		5	3	4	1	1						15
11.5				1		2	1							4
12.5				1		1								2
Totals	1	8	27	74	121	168	118	38	8	2	1	0	1	567

$r = -.231 \pm .027$.

Selections from the F_2 hybrids were grown in the F_3, both at Bozeman and Havre, Mont., where spacing of rows and plants was the same as that in the F_2. Check rows of the parent varieties alternated in every tenth row. Bulk grain samples from these nursery rows of F_3 strains and parent checks were analyzed for crude protein content. The data obtained are shown in Fig. 2.

The F_3 data from Bozeman for both the hybrids and the Marquis parent were extremely variable. This was at least partly due to soil variation. Two sections in the nursery, comprising about 15 rows each, produced low yields and "yellow berry" grain much lower in protein content than the remainder of the nursery. At Havre the soil was more uniform and the variation in protein content was not as great. As in the F_2, the average of the hybrids was intermediate to those of the parents. Also, as in the F_2, the mean of the hybrids was nearer that of the low-protein parent, Hard Federation. At Bozeman the Hard Federation averaged only slightly lower than the hybrids.

Under the favorable Bozeman conditions, the yields were high and Marquis was the better-yielding parent. At Havre, under unfavorable conditions, the yields were low and Hard Federation was the better-yielding parent.



HYBRIDS & PARENTS	NUMBER OF ROWS								TOTAL	MEAN
F_3 HYBRIDS	2	5	10	18	15	91	76	7	224	14.68
HARD FED.				2		8	3		13	14.69
MARQUIS	1		1		1	1	5	4	13	15.08

HYBRIDS & PARENTS	NUMBER OF ROWS							TOTAL	MEAN
F_3 HYBRIDS	8	18	66	89	88	28		297	15.82
HARD FED.		4	4	10				18	15.06
MARQUIS			2	2	8	4	1	17	16.76

FIG. 2.—Crude protein content of grain from F_3 strains of Marquis-Hard Federation crosses in comparison with parent check rows, grown at Bozeman and Havre, Mont., in 1924.

Under the favorable conditions at Bozeman the crude protein content of the hybrids was positively correlated with yield, as shown in Table 2. This correlation of 0.256 ± 0.042 is not large, but being over six times its error it is fairly significant. This result is opposite from that obtained in the F_2, but probably is due to the soil variation previously mentioned and to the average yields. In the F_2 the average yield of the hybrid plants was 6.7 grams, while in the F_3 the average yield was 5.0 grams. The crude protein content of the hybrids averaged 14.37% in F_2 and 14.68% in F_3. The higher yield of the F_2 was probably approaching the maximum quality limit for the particular soil condition and the increase in yield tended to lower the crude protein content of the grain. The lower yield of the F_3, on the other hand, left a greater margin of soil nutrients above the amounts necessary to produce the yield obtained, and hence averaged slightly greater in protein content.

TABLE 2.—*Correlation between average yield per plant and crude protein content of F_3 strains of Marquis-Hard Federation crosses grown at Bozeman, Mont., in 1924.*

Crude protein content	Average yield of plant in grams 2.5	3.5	4.5	5.5	6.5	7.5	8.5	Totals
10		2						2
11		5						5
12	1	2	5	1	1			10
13	1	5	7	4	1			18
14		2	7	5	1			15
15	1	10	29	26	16	8	1	91
16	1	8	30	18	17	2		76
17		2	3	2				7
Totals	4	36	81	56	36	10	1	224

r = .256 ± .042

TABLE 3.—*Correlation between average yield per plant and crude protein content of F_3 strains of Marquis-Hard Federation crosses grown at Havre, Mont., in 1924.*

Crude protein content	Average yield per plant in grams 0.8	1.3	1.8	2.3	2.8	3.3	3.8	4.3	4.8	Totals
12.5								1		1
13.0						2	4	1		7
13.5				1		3	1	2		7
14.0			1	3	1	4		1	1	11
14.5			11	5	3	6	1			26
15.0		3	17	14	5	1				40
15.5		5	16	12	5	1		1		40
16.0		10	27	12						49
16.5		16	29	6						51
17.0	1	21	14	1						37
17.5	2	15	3							20
18.0		8								8
Totals	3	78	118	54	14	17	6	.6	1	297

r = —.732 ± .018

At Havre the correlation between yield and crude protein content in the F_3 was strongly negative as shown in Table 3. The coefficient of correlation — 0.732 ± 0.018 is very important and indicates a decided negative effect of yield on quality under dry-farming conditions.

While yields at Havre were low under the unfavorable conditions which prevailed there, it is likely that the balance between yield and soil nutrition more nearly corresponded to the conditions which prevailed at Bozeman in the F_2. In the absence of definite soil data the cause of the conflicting results at Bozeman in the F_3 cannot be explained. In addition, there is not sufficient contrast in segregation to enable interpretation on a genetic basis.

The crude protein content of F_2 plants in 1923 also was correlated with that of F_3 rows in 1924. The coefficient of correlation for the Bozeman data was 0.097 ± 0.045, showing no correlation.

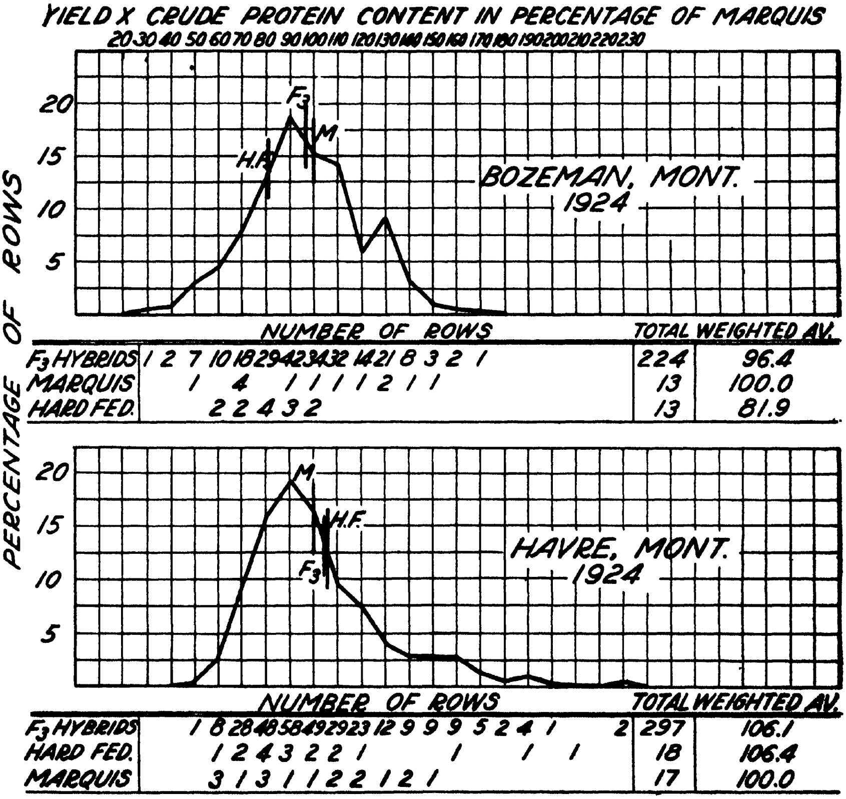
TABLE 4.—*Crude protein content of grain from individual plants of low and high F_3 strains of Marquis-Hard Federation crosses and of the parents grown at Bozeman and Havre, Mont., in 1924.*

Crude protein content	Bozeman strain and row numbers				Havre strain and row numbers			
	F_3 hybrids		Parents		F_3 hybrids		Parents	
	B3–84	B1–65	Hard Federation	Marquis	B1–65	B1–78	Hard Federation	Marquis
	145	113	20	229	203	26	300	10
8.5	2							
9.0	2							
9.5	6		1					
10.0	7		1					
10.5	3		10					
11.0	1		3					
11.5	4		3		3			
12.0	2		4					
12.5	9		3	1	2			
13.0	1		2				1	
13.5	7		3	1	2		4	
14.0	2	1	4	1	5		7	
14.5	2		3	1	9		8	
15.0	1	5	1	2	8		10	
15.5	2	5		2	4		12	
16.0		11		2	2	1	1	1
16.5		5		7	1	5	1	3
17.0		7	3	4	1	3	1	5
17.5		1	3	10		6	1	16
18.0				3		3		11
18.5						2		2
19.0				1				
Totals	51	35	44	35	37	20	46	38
Averages	11.7	16.0	12.8	16.5	14.4	17.3	14.9	17.5

Some of the F_3 and parent rows were studied on an individual plant basis. Data for the rows of greatest and least range of the hybrids and the nearest comparable parents are given in Table 4.

Many F_3 strains are significantly different in crude protein content; but because the parent rows also show significant differences, interpretation is difficult. The low-protein strains seem to be more variable than the high-protein strains, although not consistently so.

At Bozeman strain B1–65 was less variable than Marquis. This strain at Bozeman also was highest in crude protein content with 16.0%. At Havre, on the other hand, it was the lowest with 14.4%, although at this station it was the highest yielding strain studied on a plant basis. Strain B1–78, which was the highest in crude protein content at Havre, was one of the four highest in crude protein content of 567 F_2 plants at Bozeman in 1923. The data so far obtained show no F_3 families significantly higher in crude protein content than the Marquis parent, though strains were obtained which were lower than Hard Federation.



	NUMBER OF ROWS	TOTAL	WEIGHTED AV.
F_3 HYBRIDS	1 2 7 10 18 29 42 34 32 14 21 8 3 2 1	224	96.4
MARQUIS	1 4 1 1 1 1 2 1 1	13	100.0
HARD FED.	2 2 4 3 2	13	81.9

	NUMBER OF ROWS	TOTAL	WEIGHTED AV.
F_3 HYBRIDS	1 8 28 48 58 49 29 23 12 9 9 9 5 2 4 1 2	297	106.1
HARD FED.	1 2 4 3 2 2 1 1 1 1	18	106.4
MARQUIS	3 1 3 1 1 2 2 1 2 1	17	100.0

FIG. 3.—Average yield per plant x crude protein content in F_3 of Marquis-Hard Federation hybrids in comparison with parent check rows, grown at Bozeman and Havre, Mont., in 1924.

The F_2 and F_3 data as a whole indicate that crude protein content is inherited in degrees intermediate to the parents. Its mode of inheritance, like that of yield, cannot be determined. It is, moreover, evident that crude protein content is easily affected by environment and that increased yield is an important factor in decreasing the protein content.

From an agronomic standpoint quality must be combined with yield, as quality is of little importance without high yield. As a measure of the combined factors the products of plant yields and crude protein content were computed on a percentage basis, the average of all the check rows of the Marquis parent being calculated as 100%. The results are shown in Fig. 3. The data show that for combined yield and crude protein content the hybrids average between the parents but are nearer Marquis at Bozeman and nearer Hard Federation at Havre, each being the better parent at the respective stations.

TABLE 5.—*Leading F_3 strains at Bozeman and Havre as determined by the product of their yield and crude protein content.*

Station and strain	Row No.	Yield per plant in grams	Crude protein content %	Yield x crude protein content	
				Product	In percentage of Marquis
Bozeman, Mont.					
B1–102	138	8.9	15.1	134.39	175.4
B1–57	136	8.0	15.1	120.80	157.7
B3–53	117	7.9	15.1	119.29	155.7
A2–47	77	8.0	14.6	116.80	152.5
A2–57	115	7.4	15.4	113.96	148.8
B2–37	39	7.3	15.6	113.88	148.6
Best Marquis	250	7.0	16.1	112.70	147.1
Best Hard Federation	120	5.2	14.8	76.96	100.5
Average Marquis		5.0	15.1	76.61	100.0
Average Hard Federation		4.2	14.7	62.76	81.9
Havre, Mont.					
B1–51	318	4.8	14.2	68.16	230.8
B1–54	319	4.4	15.4	67.76	229.5
B2–89	324	4.3	13.6	58.48	198.0
B1–48	317	4.4	13.1	57.64	195.2
B1–57	321	4.2	13.5	56.70	192.0
B1–19	201	4.1	13.8	56.58	191.6
Best Hard Federation	335	4.2	14.7	61.74	209.1
Best Marquis	310	2.7	16.3	44.01	149.0
Average Hard Federation		2.1	15.1	31.43	106.4
Average Marquis		1.7	16.8	29.53	100.0

At both stations the best check rows of the parents are exceeded by a few hybrid strains, although whether this is a permanent improvement remains to be determined. At Bozeman approximately 35% of the hybrids averaged better than 100%, the average of Marquis, and

3 strains, or 1%, of the hybrids exceeded the best Marquis check row. At Havre nearly 35% of the hybrids exceeded 100%, the average of Marquis, while 23 strains exceeded the best check row of that parent, and 2 strains exceeded the best check row of Hard Federation.

Data for the six leading hybrid strains at each station, ranked in order of the product of yield and crude protein content on the basis of the average of the Marquis checks as 100%, are given in Table 5.

Only one strain, B1-57, ranked among the best six strains at both Bozeman and Havre. It was second at Bozeman and fifth at Havre and exceeded the best check row of Marquis by 10.6% at Bozeman and 43.0% at Havre. The greatest increase occurred under the unfavorable conditions at Havre where the six leading strains exceeded the average of Marquis check rows from 91.6 to 130.8% and the best Marquis check from 42.6 to 81.8%. Under the favorable conditions at Bozeman, the increase was less pronounced, but the six leading strains exceeded the average of Marquis check rows from 48.6 to 75.4% and the best Marquis check from 1.5 to 28.3%.

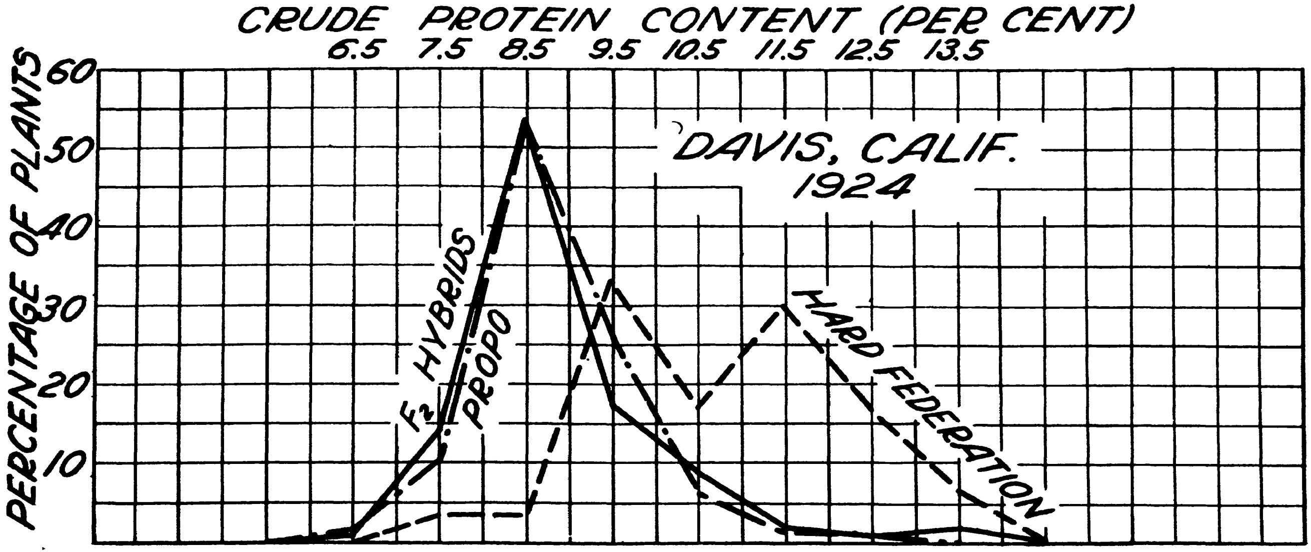
STUDIES OF HARD FEDERATION-PROPO CROSSES GROWN IN CALIFORNIA

A study similar to the foregoing has also been started with Hard Federation Propo crosses grown at Davis, California. The crops were fall-sown on summer-fallowed land under environmental conditions tending to develop wheat of low protein content. The Hard Federation variety is awnless, productive, and hard-grained, as opposed to the awned, productive, and soft-grained Propo.

Data for the crude protein content of grain from individual plants of an F_2 population grown at Davis, California, in 1924, are shown graphically in Fig. 4. The data show that the hybrids tend toward the low-protein Propo parent, indicating a dominance of the factors responsible for low protein content.

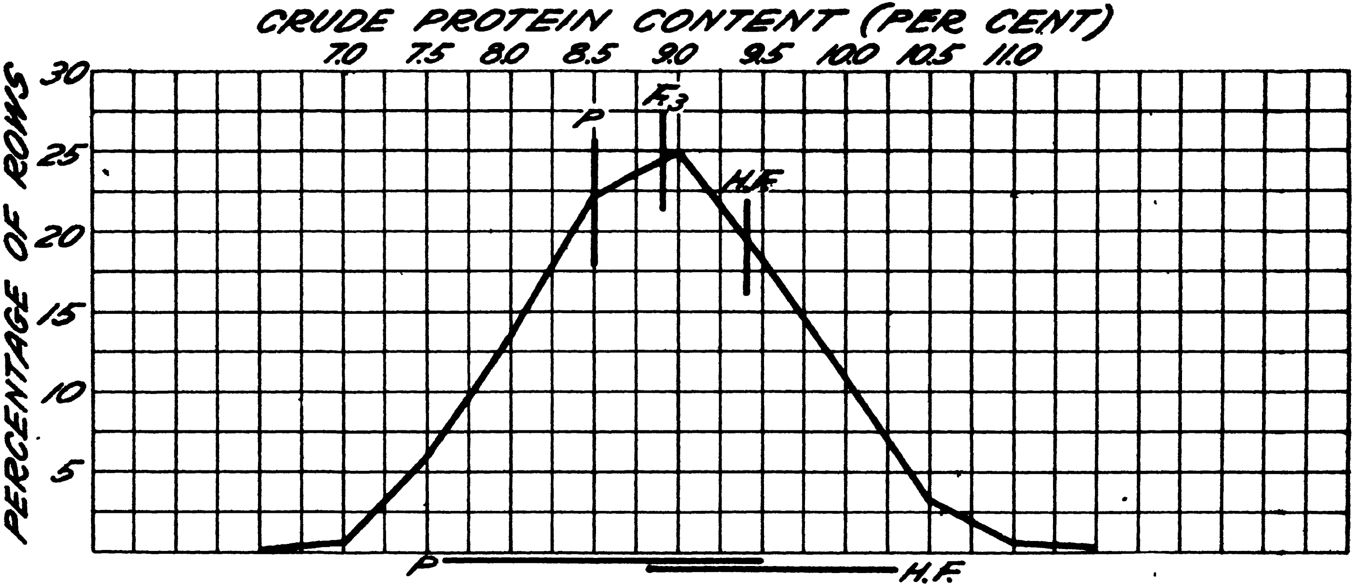
The correlation between kernel texture and protein content also was studied The grain was classified into texture classes as (1) chalky, (2) soft, (3) intermediate, (4) hard, and (5) vitreous. Samples of each class were analyzed for protein. It is recognized that these classes are arbitrary and not definite, but it is thought the data are indicative. The coefficient of correlation, 0.243 ± 0.051, is not large, yet the difference between classes 2 and 5, 0.99 ± 0.16%, is 6.2 times its error, indicating odds of more than 20,000 to 1 that the difference is significant.

Selections from the F_2 hybrids were continued in the F_3 generation. The plants were grown in single rod rows from seeds spaced



HYBRIDS & PARENTS	NUMBER OF PLANTS								TOTAL	MEAN AND P.E.
F_2 HYBRIDS	1	23	85	28	14	3	1	3	158	8.87±.0
HARD FED.		1	1	10	5	9	5	2	33	10.80±.17
PROPO	1	9	46	22	5	1	1		85	8.83±.07

FIG. 4.—Segregation in F_2 into frequency classes for crude protein content of the grain of 158 plants of Hard Federation-Propo crosses in comparison with parent plants, grown at Davis, Calif., in 1924.



HYBRIDS & PARENTS	NUMBER OF ROWS									TOTAL	MEAN
F3 HYBRIDS	1	11	26	43	48	35	21	6	1	192	8.91
PROPO		1	1	1	1	1				5	8.52
HARD FED.					3	2		1		6	9.37

FIG. 5.—Crude protein content in F_3 of Hard Federation-Propo hybrids and parent checks, grown at Davis, Calif., in 1925.

every 3 inches. Check rows of the parent varieties alternated in every twentieth row. The data obtained are shown in Fig. 5. These data differ from those for the F_2 in that the hybrids are about intermediate to the parents, indicating progress in selecting for higher protein content. Only a few hybrids equalled or exceeded the best check row of Hard Federation for crude protein content.

The average texture of the F_3 strains was found to be highly correlated with the texture of their F_2 parents, the coefficient of correlation being 0.718 ± 0.024. A similar study of the protein content of the grain from F_2 plants with the average of F_3 strains, however, gave nearly a zero correlation. This latter result agrees with the results from the Montana material. That high protein is not necessarily associated with hard texture is indicated by the lack of a significant correlation of the F_2 and the F_3, as well as by the distribution of the F_2 data which tend toward a dominance of low protein and of hard texture.

A study was also made of the relation of awnedness to yield and protein content of the grain. The spikes of the hybrid plants were classified as (1) awnless, (2) apically-awnletted, (3) awnletted, (4) short-awned, and (5) awned. The awned class (5) exceeded the yield of the awnless and apically-awnletted classes 1 and 2 by 1.47 ± 0.25 grams, or 21.4%, a significant difference as it is nearly six times its error. The awned class (5) also exceeded in crude protein content that of the awnless and apically-awnletted classes 1 and 2 by 0.77 ± 0.09, or 10.9%, a significant difference as it is 8.6 times its error.

The correlations between yield and protein content in both F_2 and F_3 were slightly positive Significant positive correlations were obtained for yield between F_2 plants and the average of F_3 rows, but for protein content similar correlations, while positive, were not large or significant.

CONCLUSIONS

It is concluded that there is segregation for crude protein content in wheat hybrids similar to that for other quantitative characters, including yield. The data indicate that the inheritance of crude protein content is as complex as that of yield and that environment is fully as important in determining the result in one case as in the other. The two characters are frequently but not always negatively associated. Kernel texture and awnedness of plants are also important factors affecting protein content. The data further show that some high crude protein F_3 strains were obtained from plant selections made in the F_2 on the basis of high crude protein content, but that such selections were not always superior to others from an F_2 plant of lower protein content.

Strains of higher crude protein content than that of the better parent were not obtained. These early inheritance studies indicate that the total amount of crude protein per acre, however, may be increased through improvement in yield with maintenance of the crude protein content of the highest parent. To increase the crude protein content of the grain materially it appears necessary to select a high-protein parent even at a sacrifice in yield.

From a plant breeding standpoint the crude protein tests should be conducted on bulk samples of the selections which appear homozygous for observable characters and are entered in rod-row nursery experiments. Elimination can then be made on the basis of yield, protein content, and the product of these factors. It is felt that such data on later generations grown in replicated nursery rows and plat experiments are necessary to prove that the total amount of crude protein per acre can be increased through the inherent characters of a new variety.

5. THE EFFECT OF ROTATION, FERTILIZERS, AND SOIL AMENDMENTS ON THE QUALITY OF COTTON FIBRE

M. F. Funchess

(Note.—This paper was read by Director Funchess as an informal discussion of the subject, and he prefers not to present a formal paper for publication in the Journal.—*Editor.*)

6. THE RELATION OF SEEDING PRACTICES TO CROP QUALITY[1]

T. A. Kiesselbach[2]

Stressing the importance of crop quality, as this symposium does, is a recognition of the fact that agronomically we are and should be interested not only in yield but in quality as well. While nearly all agronomic investigations have had to do with magnitude of production, relatively few have stressed the quality of production. One of the chief reasons for this has been perhaps, that quality of crop is not influenced in such striking fashion by many modifications of farm practice as is yield. Another deterring factor in securing extensive information along this line has been the uncertainty as to just what constitutes crop quality in the case of some crops.

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[1] Paper read as a part of the symposium on "Crop Quality" at the meeting of the Society held in Chicago, November 17, 1925. Contribution from the Department of Agronomy, Nebraska Agricultural Experiment Station, Lincoln, Nebr., as paper No. 19, Journal Series. Published with the approval of the Director.

[2] Agronomist.

Quality effects of agronomic practices become of greatest interest when considered in connection with yields. Such a combined comparison permits a balancing of yield against quality. In some instances the most sought for quality may actually be achieved through a sacrifice in yield. The producer should weigh the financial merits of a practice in terms of both factors.

Where quality can be influenced by any particular practice under consideration, the practical question arises whether the grower will be sufficiently compensated to justify his striving for that quality improvement.

From a review of the literature and unpublished results at the Nebraska Experiment Station, it becomes apparent that some seeding practices bear a very close relation to the quality of field crops, whereas other practices are negligible in their effect. Those practices which will be considered in this paper concern time, rate, and manner of seeding and seed treatment. The field crops concerned belong to the groups of cereals and forage crops.

WHAT CONSTITUTES QUALITY OF CROP

In the case of crops grown for food, either for man or livestock, soundness, keeping quality, nutritive value, palatability, low waste, and attractiveness are probably the most important considerations along with yield. For specialized purposes, some additional features are important. For example, wheat used in flour manufacture for bread making should yield a high percentage of flour possessing a high baking strength. A direct measure of baking strength is the loaf itself. The trade demands high water absorption for the dough, large loaf volume, good bread texture, and light color. Indirect methods of assessing these values commercially are color, hardness, test weight, and protein content of the grain. The reliability of some of these indirect indicators as to the actual bread baking quality of wheat is questionable. Probably so long as the grower is paid a premium for high protein content by the miller he must give it consideration, even though the miller may ultimately conclude that he has overrated the mere matter of protein percentage as an index of actual gluten quality. Some of our own wheat investigations have shown very little correlation between percentage of protein and baking strength.

Considerable confusion now exists in that the local elevator discounts the price paid for wheat for each pound under 60, while relatively lightweight "shoe peg" wheat often commands a premium at the terminal market.

SOME QUALITY FACTORS INFLUENCED BY SEEDING PRACTICES

In the case of all grains, heavy test weight per bushel is suggestive of a low percentage of crude fibre which has little feed value. Hulled cereals, such as barley and oats, ordinarily have a reduction in percentage of hull and an increase in percentage of caryopsis with increased test weight.

Moisture content and soundness are prime quality considerations in the grading of corn.

Fine stems and high percentage of leaves are desirable qualities in forage crops. They represent higher nutritive value, less waste, and greater palatability. Just what constitutes quality in recognized silage crops has not been well established. In the case of corn, a high proportion of leaves and grain is popularly thought of as increasing the feeding value.

EFFECT OF TIME OF PLANTING

CORN

Throughout most of the corn belt and in all northern states, the commercial crop of field corn is a full season crop. Its moisture content, soundness, and keeping qualities after harvest are often dependent upon the time of maturity in the fall. The time of maturity is in part related to the time of planting (Table 1). Under eastern Nebraska conditions, of which the Experiment Station is representative, the bulk of the corn crop is planted between May 10 and 25 with smaller percentages ranging 10 days earlier or later.

During the three years 1922 to 1924, two standard eastern Nebraska varieties of corn have been planted at from six to eight planting dates of approximately 10-day intervals (Table 2). During this period corn planted May 5 averaged 44 bushels per acre; May 15, 43 bushels; May 25, 40 bushels; June 4, 40 bushels; and June 14, 30 bushels per acre. During 1923 and 1924, corn was harvested from each of these plantings at various dates throughout the fall and winter for moisture and germination determinations. The results are given in Tables 1 to 4.

In 1924, the grain harvested October 10, which is the mean first killing frost date at this locality, ranged in moisture content from 22 to 53% for the May 5 to June 15 planting dates. On November 15 which is near the end of the husking season, the range in moisture content of corn left standing in the field was from 15 to 28% and the corresponding viability of the seed was 100% to as low as 54%.

TABLE 1.—*Relation of the planting date to the time of silking and maturity of dent corn.*

Nebraska Experiment Station

Date planted	Days from planting to silking				Days from silking to maturity				Percentage moisture in grain, Sept. 20, 1924
	1922	1923	1924	Average	1922	1923	1924	Average	
				Hogue Yellow Dent					
April 25	—	—	97	—	—	—	49	—	34
May 5	75	76	91	81	51	53	50	51	39
May 15	71	70	82	74	48	55	50	51	43
May 25	67	66	76	70	43	54	49	49	48
June 5	62	63	71	65	46	54	50	50	54
June 15	62	60	69	64	51	53	53	52	70
				Nebraska White Prize Dent					
April 25	—	—	100	—	—	—	51	—	42
May 5	81	79	95	85	47	54	48	50	44
May 15	76	74	85	78	43	56	48	49	45
May 25	70	70	79	73	41	54	50	48	49
June 5	65	68	73	69	45	55	51	50	65
June 15	62	63	73	66	53	55	54	54	78

TABLE 2.—*Seasonal variation in the effect of planting date upon the yield of corn at the Nebraska Experiment Station, average of two varieties, 1922–1924.*

Date planted	Yield of air-dry shelled corn in bushels per acre			
	1922	1923	1924	Average
May 5	46	45	42	44
May 15	45	43	40	43
May 25	42	46	32	40
June 4	39	52	30	40
June 14	28	56	6	30

In the preceding year, 1923, similar results were obtained. When harvested October 20, the grain ranged from 25 to 39% moisture content according to planting date. On December 6 this range in moisture was from 18 to 35% and the germination percentages fell off from 89% for May to 60% for June 14 plantings.

The direct relation between the moisture content of corn and its keeping quality and resistance to freezing injury as seed is recognized. Ear corn is not considered safe to crib until its moisture is reduced to approximately 30%. Corn containing over 15% moisture is unable to retain its viability unimpaired under the low winter temperatures of the northern corn belt states.

Williams and Welton (21)[8] of the Ohio Station report five years' results from planting dates with corn (Table 5). The five planting dates represent the entire planting season from April 24 to June 6.

TABLE 3.—*Moisture content and germination of corn harvested at different dates from plats of successive dates of planting.*

Average for two local varieties, Hogue Yellow Dent and Nebraska White Prize.

Date planted (1)	Date harvested, 1923 Oct. 20 (2)	Oct. 31 (3)	Nov. 13 (4)	Nov. 23 (5)	Dec. 6 (6)	Dec. 21 (7)	Jan. 5 (8)	Feb. 15 (9)
	Percentage moisture in ear corn							
May 8	30	25	19	19	17	18	16	18
May 16	32	26	21	19	19	18	17	19
May 25	32	28	22	20	19	19	17	18
June 6	42	35	30	25	24	20	18	19
June 14	44	39	32	25	25	21	19	19
	Percentage moisture in grain							
May 8	25	22	17	18	17	17	16	18
May 16	27	23	19	18	18	17	17	18
May 25	27	25	20	19	18	19	17	18
June 6	37	32	27	23	22	19	17	18
June 14	39	35	29	23	23	20	18	19
	Percentage moisture in cobs							
May 8	47	39	30	23	18	20	19	21
May 16	50	40	33	26	21	23	19	21
May 25	50	44	35	27	23	21	19	20
June 6	56	53	46	37	35	29	21	22
June 14	59	57	46	37	35	28	24	23
	Percentage germination							
May 8	97	94	87	86	89	86	84	79
May 16	97	90	88	84	83	88	86	79
May 25	96	95	75	85	84	83	84	53
June 6	96	81	79	79	59	60	59	40
June 14	93	80	67	71	60	60	48	39
	Minimum temperature (degrees F.)							
	31	22	22	22	18	18	—19	
	Hours below freezing							
	3	66	99	115	262	352	587	

A maximum yield of 68.5 bushels was obtained for the second planting period, May 4 to 10, while the lowest yield of 44.3 bushels was secured from the latest date. The fall moisture content of the grain was almost at the minimum for the date of highest yield and gradually increased 8.4% for the date of lowest yield. Their data also indicate an 8% lower shelling percentage in November for the delayed plantings. The improvement in quality was but very slight for seeding

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[8] Reference by number is to "Literature Cited," p. 683.

TABLE 4.—*Moisture content and germination of corn harvested at different dates from plats of successive dates of planting.*

Average for two local varieties, Hogue Yellow Dent and Nebraska White Prize.

Date planted	Date harvested, 1924							
	Sept. 10	Sept. 20	Sept. 30	Oct. 10	Oct. 20	Nov. 1	Nov. 15	Dec. 15
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Percentage moisture in ear corn							
April 25	48	43	34	25	19	15	15	15
May 5	55	45	36	28	22	16	15	16
May 17	55	48	38	31	22	15	17	17
May 26	60	52	45	33	26	17	18	18
June 5	69	63	55	47	33	24	25	21
June 16	83	79	72	64	50	40	32	30
	Percentage moisture in grain							
April 25	44	36	29	22	18	14	15	15
May 5	53	42	31	24	21	14	15	15
May 17	53	44	34	26	20	14	16	16
May 26	56	48	40	29	23	23	17	17
June 5	67	60	51	40	27	21	21	20
June 16	84	74	66	53	40	32	28	27
	Percentage moisture in cobs							
April 25	58	57	50	35	24	20	17	17
May 5	65	61	51	44	32	22	17	16
May 17	65	62	52	47	31	21	20	17
May 26	67	65	61	52	40	25	21	21
June 5	73	70	67	64	48	36	43	25
June 16	82	82	77	72	64	57	40	34
	Percentage germination							
April 25	98	99	100	99	96	99	100	96
May 5	98	100	99	100	99	98	100	89
May 17	98	99	99	99	99	99	99	91
May 26	98	98	99	99	99	99	99	95
June 5	94	97	94	97	96	93	91	86
June 16	87	87	79	82	89	87	54	49
	Minimum temperature (degrees F.)							
	48	46	34	34	34	34	20	10
	Hours below freezing							
	0	0	0	0	0	0	64	365

TABLE 5.—*Relation of the time of planting to the yield, moisture content, and shelling percentage of corn, five-year average, 1908–1913.*[a]

Ohio Experiment Station.

Planting dates	Yield of grain, bushels per acre	Percentage moisture in grain in fall	Shelling percentage in November
April 24–29	63.9	23.7	71.2
May 4–10	68.5	25.1	69.1
May 14–17	67.4	25.9	67.8
May 25–28	54.9	29.1	63.3
June 2–6	44.3	33.5	60.9

[a] From Ohio Experiment Station Bul. 282.

earlier than the maximum yield date and was obtained at a sacrifice of 4.6 bushels per acre.

From the standpoint of growing corn for feeding stock, the relative proportion of good sized ears and nubbins has little relation to feeding quality. However, from the standpoint of the seed grower who sells seed in the ear, and also from the standpoint of the labor involved in the husking, this proportion may be regarded as a factor in quality. Georgeson, Burtis, and Otis (6) of the Kansas Station found in a test of seven planting dates in 1895 that the maximum yield resulted from May 2 planting (Table 6). A gradual falling off in percentage of yield of good ears occurred with delayed seeding. Thus the total yields were 33.2 bushels for May 2 of which 74% were good ears, and 20.0 bushels for May 30 of which only 54% were good ears.

TABLE 6.—*Relation of time of planting corn to yield percentage of good ears and nubbins, 1895.*[a]

Kansas Experiment Station.

Date of seeding	No. of plats averaged	Grain per acre				
		Actual in bushels			Relative percentage	
		Good ears	Nubbins	Total	Good ears	Nubbins
April 18	5	22.3	10.5	32.8	68.0	32.8
April 25	5	22.6	9.1	31.7	71.3	28.7
May 2	5	24.4	8.8	33.2	73.5	26.5
May 9	5	23.2	7.5	30.7	75.6	24.4
May 16	5	16.0	9.0	25.0	64.0	36.0
May 23	5	10.6	8.0	18.6	57.0	43.0
May 30	5	10.7	9.3	20.0	53.5	46.5

[a] From Kansas Experiment Station Bul. 56.

WINTER WHEAT

In connection with a time of winter wheat planting experiment at the Nebraska Station (11) covering a three-year period, 1921 to 1923, information has been obtained concerning yield, weight per bushel, percentage protein, and the various milling and baking properties usually obtained in a routine milling and baking test (Table 7). The plantings were made throughout the fall and winter. The first four dates, Sept. 16, Sept. 22, Oct. 1, and Oct. 16, represent the period during which wheat is actually seeded in farm practice in this vicinity.

Comparing the crops from the two extreme dates of this planting period, Sept. 16 and Oct. 16, the latter yielded 5 bushels less grain per acre, tested 2½ pounds less per bushel, and had 2½% more protein. This increase in protein was accompanied by a decrease of 2% in the yield of flour from a bushel of grain, 5% increase in water absorption, and by no material change in loaf volume, texture, or color of bread.

TABLE 7.—*Summary of milling and baking tests of hard winter wheat in relation to time of seeding.*[a]

Average of Kanred and Nebraska No. 60 winter wheat for 3 years, 1921–1923.

Date planted	Grain weight per bushel,	Crude protein in grain	Ash in flour	Straight flour	Water used in dough	Baking results				Grain yield per acre
						Loaf Vol.	Loaf Wgt.[b]	Bread Col.	Bread Tex.	
	Pounds	%	%	%	%	cc.	*Gms.*	%	%	*Bus.*
Sept. 16	58.7	13.6	0.44	64.6	59	2030	458	98	99	28.8
Sept. 22	58.5	13.8	0.43	64.4	62	2058	455	97	100	32.2
Oct. 1	57.8	14.5	045	63.6	62	1987	455	97	97	28.3
Oct. 16	56.7	16.1	0.47	62.4	63	2035	450	96	98	23.8
Oct. 31	56.3	16.6	0.47	62.0	64	2048	460	98	97	20.5
Nov. 25	56.1	16.5	0.47	61.7	64	2010	466	98	98	17.4
Feb. 13	54.8	16.7	0.47	60.4	65	2052	469	98	98	12.2

[a] From Nebraska Experiment Station Res. Bul. 31.

[b] Average for 1921 only.

TABLE 8.—*Relation of the time of seeding and the yield, test weight, and protein content of Turkey Red winter wheat.*[a]

Average for five years, 1919–1923, Nebraska Experiment Station.

Average date planted	Yield of grain per acre	Weight per bushel	Protein, moisture-free basis
	Bushels	*Pounds*	%
September 16	32.1	59.2	13.8
September 22	34.2	58.7	14.1
October 1	32.2	58.4	14.6
October 16	25.1	56.9	15.8
October 31	20.2	55.9	16.0
November 25	16.7	54.8	15.9
February 13	11.8	52.2	16.2

[a] From Nebraska Experiment Station Res. Bul. 31.

During the five-year period 1919 to 1923 (Table 8), the test weight, protein content, and yield per acre were obtained for Turkey Red winter wheat planted on seven different dates at the Nebraska Station (11). The yield dropped 17.5 bushels or 51% from Sept. 22 seeding to Nov. 25 seeding. This was accompanied by 1.8% increase in protein content but 3.9 pounds reduction in test weight.

Although a premium is sometimes paid for winter wheat having a high percentage of yellow berry in those seasons when a shortage exists in the production of the "soft red wheats," this yellow berry character is commonly regarded as inferior quality and is discriminated against. Roberts and Freeman (18) of the Kansas Experiment Station have shown a striking reduction from 54% to 20% of yellow berry with delayed seeding from Sept. 28 to Oct. 16 (Table 9). Roberts has reported no yields for this test and we do not know whether this improvement in quality due to delayed seeding was accompanied by a sacrifice in yield.

Coffman (3) reports three years' results (Table 10) at the Akron, Colorado, Station for Kanred winter wheat seeded at five dates between Aug. 16 and Oct. 17. On summer fallow land the yield dropped from 24.8 bushels to 14.3 bushels with delayed seeding, while the test weight fell 2.8 pounds per bushel. So nearly the maximum yield and test weight fell upon the same planting date as to suggest aiming for maximum yield with the expectation that satisfactory quality will follow. On corn land both maximum yield and maximum test weight fell on the same date.

TABLE 9.—*Relation of the date of planting and the duration of the fall vegetative period to the percentages of yellow berry, 1905–1906.*[a]

Kansas Experiment Station.

Date of planting	Number of cases	Number of days of fall vegetative period	Mean temperature, degrees F.	Average percentage of yellow berry
Sept. 28	9	94	45.47	53.80
Sept. 29	15	93	44.91	45.43
Sept. 30	24	92	44.84	27.20
Oct. 2	51	90	44.53	35.74
Oct. 11	4	81	42.09	22.25
Oct. 16	24	76	41.07	19.58

[a] From Kansas Experiment Station Bul. 156.

TABLE 10.—*Relation of the time of planting to the yield and test weights of Kanred winter wheat.*[a]

Average for three years, 1920–1922, Akron, Colorado, Experiment Substation.

Date of seeding[b]	Yield per acre, bushels	Weight per bushel, pounds	Yield per acre, bushels	Weight per bushel, pounds
August 16–18	24.8	59.1	12.5	57.8
September 1–4	25.8	58.0	18.9	57.9
September 16	20.4	57.7	18.9	58.0
October 1	11.9	56.0	8.1	56.8
October 15–17	14.3	56.3	10.0	57.4

[a] From United States Dept. of Agr. Bul. 1287.

[b] Five rates averaged for each date.

TABLE 11.—*Relation of the time of seeding to the yield and test weight of winter wheat.*[a]

Kansas Experiment Station.

Date of seeding	Yield of grain per acre, bushels	Weight per bushel, pounds
August 31.......	13.3	52.8
September 7......	14.4	51.8
September 16.....	16.1	53.0
September 21.....	13.8	49.4
September 28.....	10.6	45.9
October 5........	2.9	41.2

[a] Kansas Experiment Station Bul. 71.

Georgeson, Burtis, and Otis (7) of the Kansas Station report the test weight and yield of winter wheat for six fall seeding dates during one year (Table 11). The results indicate that the highest test weight was acquired at the date giving maximum yield. Wheat seeded Sept. 16 tested 53 pounds and yielded 16 bushels, while wheat seeded Oct. 5 tested only 41 pounds and yielded 3 bushels per acre.

The relation of stinking smut or bunt infection to time and depth of seeding has been worked out for Washington conditions and reported (Tables 12 and 13) by Woolman and Humphrey (22), and by Heald and Woolman (8). Such control is possible primarily because of the differential reaction of host and pathogene to temperature. Shallow planting done either very early or very late produced a crop relatively free of smut. The results of these investigators deal with percentage of infection only.

The correlation of such smut control through time of seeding is developed for Washington conditions (Table 14) by Schafer, Gaines, and Barbee (19). The authors indicate that, "Very early or very late seeding will reduce the percent of smut, but it will also reduce the yield of wheat. The time to seed wheat should not be governed entirely by the amount of smut produced, as conditions favoring increased smut production in a large measure favor increased yields of wheat."

TABLE 12.—*Combined effect of time and depth of planting upon the percentage of smut or bunt from clean treated seed of Hybrid 143 winter wheat seeded in bunt-infected soil, 1915.*[a]

Washington Experiment Station.

Date of planting	Depth sown, inches	Clean treated seed on bunt-infected soil: Total number of plants	Percentage plants bunted	Percentage heads bunted	Smutty seed on soil not artificially inoculated: Total number of plants	Percentage plants bunted	Percentage heads bunted
Sept. 1	0.5	216	3.7	3.5	277	4.0	0.8
	1.5	229	12.2	20.6	258	5.0	1.9
	3.0	100	21.0	22.2	105	7.6	2.8
Oct. 4	0.5	220	50.1	49.9	238	28.2	11.9
	1.5	229	76.4	61.7	296	96.0	92.4
	3.0	215	87.0	81.6	290	98.3	96.9

[a] From United States Dept. of Agr. Bul. 1239.

As an average for these tests a maximum yield of 36.4 bushels was obtained from Sept. 1 seeding and the crop contained 5% smut. Seeding Aug. 1 yielded 6.3 bushels less but contained only 1.3% smut. When seeded Sept. 15, a maximum amount of smut, 11.4%, prevailed and the yield was 7.1 bushels below that of Sept. 1. Seed-

TABLE 13.—*Relation of the depth of seeding to bunt infection at Pullman, Washington, in 1914.*[a]

Washington Experiment Station.

Date of seeding	Depth sown, inches	Early Wilbur wheat Total number of plants	Percentage plants bunted	Percentage heads bunted	Hybrid 143 Total number of plants	Percentage plants bunted	Percentage heads bunted
	Inoculated untreated seed wheat sown in bunt-free soil						
March 17	0.5	181	51.0	34.9	30	58.8	—
	1.0	168	92.2	88.8	45	64.6	—
	1.5	190	99.5	98.5	77	54.6	—
	2.0	181	98.9	98.4	78	78.2	66.1
	2.5	189	100.0	100.0	129	87.6	79.3
	3.0	185	99.5	99.7	196	90.8	83.9
	Clean treated wheat sown in artificially inoculated soil						
March 19	0.5	104	65.4	47.8	149	21.4	16.8
	1.0	120	81.7	66.4	161	48.4	35.0
	1.5	79	88.6	75.2	94	58.5	39.8
	2.0	58	87.9	83.8	96	73.9	60.0
	2.5	62	96.7	92.1	69	84.1	74.8
	3.0	49	95.9	91.2	59	84.8	80.9

[a]From United States Dept. of Agr. Bul. 1239.

ing as late as Dec. 1 during two years, 1918 and 1919, reduced the average percentage of smut to 0.1 compared with the maximum infection of 10.7% for Sept. 15, but the yield was lowered from 43.8 bushels to 29.9 bushels. Striving for such minimum of smut by extremely delayed seeding would be unjustifiable in view of the decided reduction in yield.

The seed planted had received a standard treatment for smut and the infection represents that from smut spores carried in the soil from the preceeding crop. This condition does not prevail in most of the

TABLE 14.—*Relation of the time of planting to the yield and percentage of stinking smut or bunt of winter wheat.*[a]

Average for three years, 1917–1919, Washington Experiment Station.[b]

Date planted	Hybrid 128 Yield per acre, bushels	Smut %	Red Russian Yield per acre, bushels	Smut %	Average Yield per acre, bushels	Smut %
August 1	36.0	2.1	24.2	0.5	30.1	1.3
August 15	40.5	2.7	29.5	0.5	35.0	1.6
September 1	40.6	8.0	32.2	2.1	36.4	5.0
September 15	32.5	16.2	26.2	6.6	29.3	11.4
October 1	34.8	12.1	22.6	8.8	28.7	10.4
October 15	27.3	7.2	15.9	5.4	21.6	6.3
November 1	33.8	5.6	26.2	3.3	30.0	4.4

[a]The seed planted had received a standard treatment for smut.

[b]From Washington Experiment Station Bul. 159.

wheat territory of the United States, and therefore seed treatment provides an effective control. These data are of interest here because high smut infection is recognized as reducing grain quality.

SPRING WHEAT, OATS, AND BARLEY

Java spring wheat seeded at the Nebraska Experiment Station (13) during seven years, 1917–1923, on normal, medium, and late dates in the spring, *viz.*, March 31, April 12, and April 20, averaged 15.8, 12.1, and 9.0 bushels per acre and had respective test weights of 55.6, 53.8, and 51.7 pounds per bushel (Table 15).

TABLE 15.—*Effect of the time of planting upon the yield and test weight of Java spring wheat, seven-year average, 1917–1923.*[a]

Nebraska Experiment Station.

Time of planting Relative	Time of planting Date	Date in head	Date ripe	Length of growing period in days	Weight of grain per bushel, pounds	Yield of grain per acre Actual in bushels	Yield of grain per acre Relative percentage
Early	Mar. 31	June 15	July 10	101	55.6	15.8	100.0
Medium	Apr. 12	June 19	July 13	93	53.8	12.1	76.6
Late	Apr. 20	June 22	July 16	87	51.7	9.0	57.0

[a]From Nebraska Experiment Station Bul. 201.

TABLE 16.—*Effect of the time of planting upon the yield and test weight of Kherson oats, seven-year average, 1917–1923.*[a]

Nebraska Experiment Station.

Time of planting Relative	Time of planting Date	Date in head	Date ripe	Length of growing period in days	Weight of grain per bushel pounds	Yield of grain per acre Actual in bushels	Yield of grain per acre Relative percentage
Early	Mar. 31	June 12	July 3	94	29.1	58.2	100.0
Medium	Apr. 12	June 14	July 6	85	27.8	49.4	84.9
Late	Apr. 20	June 19	July 10	81	27.4	38.6	66.3

[a]From Nebraska Experiment Station Bul. 201.

In a corresponding test with Kherson oats, early, medium, and late planting yielded 58.2, 49.4, and 38.6 bushels per acre, respectively, and had test weights of 29.1, 27.8, and 27.4 pounds, respectively (Table 16).

Burnett (2) of Iowa found in 1916 that oats seeded April 15 and April 27 yielded 59 and 37 bushels of grain, respectively (Table 17). The corresponding test weights were 26.9 and 24.3 pounds per bushel.

Burlison and Stark (1) of Illinois report the relation of seeding date in 1919 to the yield, test weight, and percentage of scab for two varieties of spring wheat (Table 18). The seeding dates were March 6, 16, 29, and April 10. The yield and test weight uniformly and materially receded, while the percentage of scab increased with delayed planting. All considerations were in favor of early planting.

Hendry (9) of the California Station (Table 19) found, in 1919, that planting barley in September, November, January, and March yielded respectively 60, 80, 82, and 31 bushels per acre and tested 37, 45, 40, and 36 pounds per bushel.

TABLE 17.—*Relation of the time of seeding to yield and test weight of oats, 1916.*[a]

Iowa Experiment Station.

Date of seeding	Number of plats averaged	Yield per acre in bushels	Weight per bushel in pounds
April 15	9	59.4	26.9
April 27	9	36.8	24.3

[a]Iowa Experiment Station Bul. 175.

TABLE 18.—*Relation of the time of seeding to the yield and quality of spring wheat, 1919.*[a]

Illinois Experiment Station.

Date of planting	Illinois No. 1 wheat: Yield per acre in bushels	Illinois No. 1 wheat: Weight per bushel in pounds	Illinois No. 1 wheat: Percentage of scab	Marquis wheat: Yield per acre in bushels	Marquis wheat: Weight per bushel in pounds	Marquis wheat: Percentage of scab
March 6	28.9	60.8	1.0	29.6	59.0	2.0
March 16	23.5	59.4	0.8	27.3	58.0	6.0
March 29	21.8	58.8	5.6	23.8	56.5	7.4
April 10				22.2	54.8	14.8

[a]From Illinois Experiment Station Bul. 214.

TABLE 19.—*Relation of time of planting to the yield and test weight of barley, 1919.*[a]

California Experiment Station.

Date of planting	Weight of grain per bushel in pounds	Yield of grain per acre in bushels
September 18	37	60
November 6	45	80
January 8	40	82
March 22	36	31

[a]From California Experiment Station Bul. 312.

TABLE 20.—*Relation of the planting date to the yield and test weight of barley and oats, 1906.*[a]

Kansas Experiment Station.

Date of seeding	Weight per bushel in pounds: Barley	Weight per bushel in pounds: Oats	Yield per acre in bushels: Barley	Yield per acre in bushels: Oats
Feb. 1	34.0	27.0	36.6	29.7
Feb. 19	35.0	27.0	30.2	36.3
Mar. 29	28.7	25.5	18.5	43.8
April 10	22.0	27.0	18.8	43.0
April 21	25.0	32.0	11.3	23.8
April 28	29.5	29.5	18.3	17.6
May 11	...	25.5	5.8	31.3

[a]From Kansas Experiment Station Bul. 144.

Ten Eyck and Shoesmith (20) reported results for one year, 1906, from seeding barley and oats at seven successive dates in the spring, namely, Feb. 1 to May 11 (Table 20). The data suggest that from the combined standpoint of yield and quality, early seeding is desirable.

EFFECT OF RATE OF PLANTING

CORN

In a seven-year test at the Nebraska Experiment Station (10), 1911 to 1917, a local variety of corn, Hogue Yellow Dent, was grown at the three planting rates of 1, 3, and 5 plants per hill in hills spaced 42 inches apart (Table 21). The 3-plant rate is normal for this region. The shrinkage and shelling percentage were almost constant for all rates, while the extreme range in yields was 8 bushels per acre.

In a similar eight-year test with another variety, Nebraska White Prize, no significant differences occurred in shrinkage or shelling percentages, though there was an extreme variation in yield of 15.8 bushels per acre.

Although the ears were approximately only half as large for the 5-plant as for the 1-plant rate, the quality from the standpoint of food value was probably equal.

The Ohio Station (21) compared the average weight of ears and percentage of nubbins grown under the five planting rates of 1 to 5 plants per hill during a 10-year period, 1904–1914 (Table 22). Ears produced in the thickest rate were ⅔ as large as for the thinnest rate. Likewise the crop contained 43% nubbins for the 5-plant rate and only 16% for the 1-plant rate. Since ear weight and percentage nubbins are not true factors in the intrinsic quality of the crop, the most practical rate proved to be 4 plants per hill, giving a yield of 65 bushels per acre which was 4 bushels higher than the next lower rate and approximately double the 1-plant rate.

In a four-year test at the Nebraska Station (12), 1921–1924, of growing drilled corn at the six planting rates of 1, 2, 3, 4, 5, and 6 plants per hill, the percentage of grain in the silage fell off from 40 to 32% with increased planting (Table 23). The maximum yield of silage was grown at 4 plants per hill, but silage with the highest percentage of grain was grown at the rate of 1 plant per hill. The superiority of silage yield for the 3- and 4-plant rates was sufficient to justify growing silage at those rates in spite of the reduction in percentage of grain. Thicker seeding both reduced the yield and percentage of grain.

In connection with four different spacings of corn for silage, ranging from 4 to 12 inches between plants, the Ohio Station found very little effect upon the composition of the silage (Table 24). The thickest rate yield was 1.4 tons more per acre than any other rate, and this is the deciding factor in this test.

TABLE 21.—*Relation of planting rate to the yield and quality of corn.*[a]
Nebraska Experiment Station.

Plants per hill	Plants per acre	Ears per 100 plants	Weight per ear, pounds	Percentage shrinkage of ear corn	Shelling percentage	Yield of grain per acre in bu.
Hogue Yellow Dent corn (seven years, 1911–1917)						
1	3,556	170	0.42	10.5	83.2	36.6
3	10,668	86	0.32	10.1	83.6	44.6
5	17,780	63	0.24	10.3	82.1	40.3
Nebraska White Prize (eight years, 1915–1917 and 1920–1921)						
1	3,556	148	0.49	7.7	80.8	37.1
3	10,668	104	0.32	7.7	81.4	52.9
5	17,780	78	0.25	7.9	81.2	49.4

[a] From Nebraska Experiment Station Res. Bul. 20.

TABLE 22.—*Relation of the rate of planting corn to yield, average ear weight, and percentage of nubbins, average 1910–1914.*[a]
Ohio Experiment Station.

Number of plants per		Yield of grain per acre in bushels	Average weight per ear in pounds	Percentage of of nubbins
Hill	Acre			
1	3,555	32	0.66	16
2	7,110	51	0.64	17
3	10,665	61	0.56	22
4	14,220	65	0.47	31
5	17,775	63	0.41	43

[a] From Ohio Experiment Station Bul. 282.

TABLE 23.—*Relation of the rate of planting corn to the yield and percentage of grain in silage.*[a]
Nebraska Experiment Station.

Rate of planting[b]	Leaf area per stalk[c] in square inches	Stalk diameter at base in inches	Proportion of leaf weight to plant weight %	Yield of grain per acre, air-dry basis		Yield of silage per acre (15% moisture basis)		Grain in silage (15% moisture basis) %
				Actual in bushels	Relative percentage	Tons	Relative %	
Rate 1	1,385	1.28	12.7	26.1	100	1.84	100	40
Rate 2	1,353	1.19	13.7	40.5	155	2.81	153	40
Rate 3	1,346	1.08	14.6	44.5	170	3.18	173	39
Rate 4	1,241	1.02	14.8	43.6	167	3.44	187	35
Rate 5	1,203	0.95	16.4	43.2	166	3.36	183	36
Rate 6	1,167	0.94	16.3	37.7	144	3.29	179	32
Average	1,282	1.08	14.7	39.3		2.99	—	—

[a] From Nebraska Experiment Station Bul. 206.

[b] Planted at rates corresponding to 1, 2, 3, 4, 5, and 6 plants per hill 42 inches apart.

[c] An average of 20 plants per rate for the three years, 1921–1923.

TABLE 24.—*Relation of rate of planting to the yield and composition of corn silage, average for five years, 1909–1913.*[a]

Ohio Experiment Station.

Space between plants, inches	Yield of silage per acre, tons	Composition of silage Protein %	Crude fiber %	Nitrogen-free extract %	Fat %
4	15.7	1.6	7.0	15.1	0.32
6	14.3	1.5	5.7	12.3	0.27
10	13.5	1.7	5.8	13.5	0.34
12	12.9	1.8	6.0	13.0	0.31

[a] From Ohio Experiment Station Bul. 82.

WINTER WHEAT

Winter wheat grown at the Nebraska Station (11) during five years, 1919–1923, at the five planting rates of 3, 4 5, 6, and 8 pecks per acre, ranged in yield from 28.6 bushels for the thinnest to 31.5 bushels for the 6-peck rate (Table 25). The protein ranged from 13.1 to 13.4% and the test weight was identical, namely, 58 pounds for all.

In tests carried on by the Office of Cereal Investigations at the Akron, Colorado, Experiment Station, Coffman (3) found a gradual increase of 1 pound in test weight and 6.9 bushels in yield of Kanred winter wheat per acre as the rate of seeding was increased from 1 to 5 pecks per acre on summer-tilled land. The same general results were secured on corn land (Table 26). During the six-year period, 1913–1918, at the Akron Station (Table 27) winter wheat was seeded at the rates of 1, 2, 3, 4, 5, and 6 pecks per acre. The extreme variation in test weight was less than 1 pound with maximum weight occurring at the heaviest rate. The maximum yield per acre was likewise obtained at the 6-peck rate, having gradually risen to 23.6 bushels from 14.7 bushels for the 1-peck rate.

TABLE 25.—*Relation of rate of planting to the growth and yield of Turkey Red winter wheat, five-year average, 1919–1923.*[a]

Nebraska Experiment Station.

Rate of planting per acre	Plant height, inches	Date ripe	Stools per plant in fall	Stools per plant May 15	Weight of grain per bu., pounds	Protein in grain (moisture-free basis), %	Yield of grain per acre, bushels
Three pecks	37	7/2	5.0	4.3	58	13.1	28.6
Four pecks	36	7/1	4.4	3.2	58	13.1	30.4
Five pecks	36	7/1	4.1	2.6	58	13.1	30.5
Six pecks	36	7/1	3.8	2.5	58	13.2	31.5
Eight pecks	35	7/1	3.3	1.8	58	13.4	30.7

[a] Nebraska Experiment Station Res. Bul. 31.

TABLE 26.—*Relation of the rate of planting to yield and test weight of Kanred winter wheat, average for three years, 1920–1922.*[a]
Akron, Colorado, Field Station.

Rate of planting per acre	Fallow land		Corn land	
	Weight per bushel in pounds	Yield per acre in bushels	Weight per bushel in pounds	Yield per acre in bushels
One peck	56.9	15.7	56.9	11.0
Two pecks	56.9	18.4	57.2	12.5
Three pecks	57.7	20.1	57.8	14.2
Four pecks	57.8	21.4	58.0	14.9
Five pecks	57.9	21.6	58.2	15.8

[a]From United States Dept. of Agr. Bul. 1287.

TABLE 27.—*Relation of the rate of planting to yield and test weight of winter wheat, average for six years, 1913–1918.*[a]
Akron, Colorado, Field Station.

Rate of planting per acre	Weight of grain per bushel in pounds	Yield of grain per acre in bushels
One peck	58.5	14.7
Two pecks	58.0	19.1
Three pecks	58.3	20.5
Four pecks	58.2	20.6
Five pecks	58.1	21.9
Six pecks	58.7	23.6

[a]From United States Dept. of Agr. Bul. 1287.

SPRING WHEAT, OATS, AND BARLEY

The Nebraska Station compared seven seeding rates with an early- and a late-maturing variety of oats during a six-year period, 1917–1923 (Table 28). Within the range of seeding rates practiced on farms the test weight was but little influenced by the seeding rate, even though the yield was materially affected. The extreme variation in yield between the different rates of seeding Kherson oats was 5 bushels and for Swedish Select 10 bushels per acre, while the extreme variation in test weight was 1.1 pounds for Kherson and 0.7 pound for Swedish Select.

Similar tests at Akron (3), Colorado, with durum wheat during the 11-year period, 1911–1922, and with Kherson oats during the 9 year period 1911–1919 indicate that nearly maximum test weights are to be expected at those planting rates which also give maximum yields (Tables 29 and 30).

Nelson and Ruzek (17) of Arkansas found in a comparison of seven seeding rates ranging from 4 to 16 pecks per acre that yield per acre gradually and regularly increased from 30.2 bushels to 44.9 bushels per acre as the rate increased. The test weight also increased gradually from 24.4 pounds for the 4-peck rate up to 27.2 pounds for the 12-peck rate, and then fell off only 0.6 pound for the

16-peck rate. The three heaviest seedings gave the maximum yields and likewise the highest test weights.

TABLE 28.—*Relation of rate of planting early- and late-maturing varieties of oats to the yield per acre and test weight of the grain, six-year average, 1917–1923.*[a]

Nebraska Experiment Station.

Rate per acre in pecks	Date ripe	Weight per bushel in pounds	Yield per acre Actual in bushels	Yield per acre Net in bushels
Kherson (early variety with small seeds)				
4	July 7	30.6	48.2	47.2
6	July 7	31.3	51.8	50.3
8	July 6	31.3	52.2	50.2
10	July 6	31.4	53.0	50.5
12	July 6	31.6	53.2	50.2
14	July 6	31.7	52.4	48.9
16	July 5	31.4	50.4	46.4
Regenerated Swedish Select (late variety with large seeds)				
4	July 12	31.6	39.6	38.6
6	July 12	31.9	44.6	43.1
8	July 12	31.6	46.9	44.9
10	July 11	32.1	48.4	45.9
12	July 11	31.5	49.3	46.3
14	July 10	31.6	48.2	44.7
16	July 10	31.4	48.4	44.4

[a] From Nebraska Experiment Station Bul. 201. No results secured for 1918.

TABLE 29.—*Relation of the rate of planting to yield and test weight of Durum wheat, average for eleven years, 1911–1922.*[a]

Akron, Colorado, Field Station.

Rate of seeding per acre	Weight of grain per bushel in pounds	Yield of grain per acre in bushels
Two pecks	59.2	15.6
Three pecks	58.7	16.3
Four pecks	58.8	16.9
Five pecks	58.8	16.4
Six pecks	57.5	16.5

[a] From United States Dept. of Agr. Bul. 1287.

TABLE 30.—*Relation of rate of planting to yield and test weight of Kherson oats on fallow land, average for nine years, 1911–1919.*[a]

Akron, Colorado, Field Station.

Rate of seeding per acre	Weight of grain per bushel in pounds	Yield of grain per acre in bushels
Two pecks	29	35.0
Three pecks	29	37.4
Four pecks	29	38.7
Five pecks	30	39.6
Six pecks	30	40.1

[a] From United States Dept. of Agr. Bul. 1287.

TABLE 31.—*Relation of the rate of planting to the yield and test weight of oats, average for five years, 1909–1913.*[a]
Arkansas Experiment Station.

Rate of seeding per acre	Weight of grain per bushel in pounds	Yield of grain per acre in bushels
Four pecks	24.4	30.2
Six pecks	24.9	35.9
Eight pecks	25.7	36.0
Ten pecks	25.5	41.6
Twelve pecks	27.2	43.9
Fourteen pecks	27.1	44.1
Sixteen pecks	26.6	44.9

[a] From Arkansas Experiment Station Bul. 118.

FORAGE CROPS

In a comparative test with sorghum and Sudan grass grown for forage at six different seeding rates (Tables 32 and 33), the Nebraska Station (12) found a rather gradual reduction in stem diameter and an increase in percentage of leaves as the seeding rate was increased. On the basis of yield per acre, coarseness of stem, and fodder analysis, it may be concluded that cane is advantageously seeded very thick in this region, namely, 120 to 150 pounds per acre. Although the yield of cane was not very materially affected by increase in seeding rate

TABLE 32.—*Relation of seeding rate to the yield, coarseness, and leafiness of cane and Sudan grass forage, average for three years, 1922–1924.*[a]
Nebraska Experiment Station.

Crop and rate of seeding per acre	Yield of cured hay per acre, tons	Stalks per 10 feet of drill row	Weight of 100 stalks in pounds	Proportion of parts			Stem diameter at base	
				Stems %	Leaves %	Heads %	Inches	Relative %
Black Amber sorghum								
25 pounds	4.17	69	3.11	47.1	32.1	20.8	0.25	100
50 pounds	4.51	97	2.05	47.4	34.7	17.9	0.20	80
75 pounds	4.27	111	.85	48.6	34.1	17.3	0.19	76
100 pounds	4.55	136	.52	47.2	35.6	17.2	0.16	64
125 pounds	4.42	153	.21	48.2	38.4	13.4	0.15	60
150 pounds	4.45	182	.03	46.5	38.2	15.3	0.13	52
Average	4.40	125	.79	47.5	35.5	17.0	0.18	
Sudan grass								
10 pounds	3.32	116	.46	50.2	29.8	20.0	0.17	100
20 pounds	3.49	157	.14	49.3	32.1	18.6	0.16	94
30 pounds	3.65	186	.19	51.4	30.3	18.3	0.15	88
40 pounds	3.66	211	0.94	50.0	33.6	16.4	0.14	82
60 pounds	3.69	261	0.70	48.1	34.9	17.0	0.12	71
80 pounds	3.48	312	0.72	49.5	34.5	16.0	0.11	65
Average		207	1.02	49.7	32.5	17.7	0.14	

[a] From Nebraska Experiment Station Bul. 206.

above 50 pounds per acre, yet the quality of forage was greatly improved by reducing the coarseness of stem.

Sudan grass yielded at almost a maximum rate of cured forage when seeded as light as 30 pounds per acre, and it grows so much finer stemmed than cane that this is regarded as the most satisfactory rate for these conditions, even though the crop continues to reduce in coarseness by heavier seedings.

TABLE 33.—*Effect of the seeding rate of Black Amber sorghum and Sudan grass upon the chemical composition of the hay produced, 1924.*[a]

Nebraska Experiment Station.

Crop and rate of seeding per acre	Stem diameter at base in inches	Fodder analyses, moisture-free basis				
		Ash %	Crude protein %	Crude fiber %	Nitrogen-free extract %	Fat %
Black Amber sorghum						
25 pounds	0.24	5.62	3.42	25.10	63.92	1.94
50 pounds	0.19	6.15	3.52	27.00	61.18	2.15
75 pounds	0.18	5.72	2.97	26.80	62.52	1.99
100 pounds	0.17	5.56	2.58	27.20	62.38	2.28
125 pounds	0.14	6.04	2.89	28.90	60.04	2.13
150 pounds	0.13	5.82	2.79	28.20	61.09	2.10
Average	0.17	5.82	3.03	27.20	61.85	2.10
Sudan grass						
10 pounds	0.15	7.46	2.48	36.20	52.02	1.84
20 pounds	0.13	6.84	2.78	32.60	55.95	1.83
30 pounds	0.11	6.96	2.58	34.80	53.94	1.72
40 pounds	0.10	7.04	2.98	32.70	55.79	1.49
60 pounds	0.09	6.68	2.28	37.40	52.26	1.38
80 pounds	0.08	6.82	2.74	33.90	54.74	1.80
Average	0.11	6.97	2.64	34.60	54.12	1.68

[a] From Nebraska Experiment Station Bul. 206.

MANNER OF SEEDING

In some sections of the country drilling small grain crops is highly favored over broadcasting. It averages higher in yield because of more uniform covering and germination of the seed. This tends somewhat to increase the uniformity of ripening and results in slightly heavier test weight. This may be illustrated in a very mild degree by five-year tests, 1919–1923, with oats and winter wheat (Table 34) at the Nebraska Station (11 and 13). Broadcast oats yielded 0.5 bushel less than drilled oats and tested 0.3 pound less. Winter wheat yielded 5.3 bushels less when broadcast and tested 0.4 pound less.

SMUT TREATMENT FOR WHEAT

Stinking smut has spread rapidly in recent years throughout much of the wheat belt with the effect of lowering both yields and quality.

TABLE 34.—*Drilling vs. broadcasting Turkey Red winter wheat and Kherson oats in relation to yield and test weight of grain, five-year average, 1919–1923.*[a]

Nebraska Experiment Station.

Manner of planting	Space between rows in inches	Oats, 5-year average 1917–1920–1923		Winter wheat, 5-year average, 1919–1923	
		Yield per acre in bushels	Weight per bushel in pounds	Yield per acre in bushels	Weight per bushel in pounds
Broadcast	—	61.4	31.3	24.4	57.3
Drilled	8	63.6	31.6	29.7	57.7
Drilled	4	—	—	29.8	58.1

[a]From Nebraska Experiment Station Bul. 201 and Res. Bul. 31.

It is not uncommon for untreated seed to produce 10 to 30% of smutted heads, and some fields in the hard winter wheat belt have been left unharvested because of severe smut infection.

The wet formalin treatment has been effective but is relatively inconvenient to apply and is unpopular. The recently introduced dry copper carbonate dust treatment, on the other hand, is proving attractive to farmers because of its simpler application. In one county of Nebraska alone 2,000 pounds of copper carbonate were used this past season—sufficient to treat 16,000 bushels of seed. Much information concerning this new treatment, which appears to have been first used by Darnell-Smith (5) in 1919 in Australia, has been contributed by Mackie and Briggs (16) of California, Lambert and Bailey (15) of Minnesota, and Coons (4) of Michigan. Tests conducted at the Nebraska Station (10) in 1924 illustrate well the effects of smut control through both the copper dust and formalin treatments (Tables 35 and 36). Kanred seed wheat representing three grades of infection was used. It had been threshed from three fields containing, respectively, (a) 0.5% smut, (b) 10% smutted heads, and (c) 20% smutted heads. These lots yielded 35, 28, and 21 bushels per acre, respectively; tested 60, 55, and 53 pounds per bushel; and had 0.5, 38, and 63% smutted heads in the crop.

TABLE 35.—*Relation of degree of smut infection to test weight of crop yield of grain per acre, Kanred winter wheat, 1924.*[a]

Nebraska Experiment Station.

Degree of seed infection	Crop harvested in 1924		
	Smutted heads in field, %	Weight per bushel in pounds	Yield per acre in bushels
None	0	60.5	34.7
Slight	3	59.5	31.8
Medium	8	59.0	28.2
Severe	12	58.0	26.5
Very severe	42	55.0	20.7
Extreme	53	50.0	16.3

[a]From Nebraska Experiment Station Res. Bul. 31.

When treated with formaldehyde, these three lots of seed yielded, respectively, 36, 33, and 35 bushels; contained 0.2, 1.0, and 2% of smutted heads; and all tested 59 pounds per bushel. Treated with copper carbonate, containing 50% copper, the yields were 36, 34, and 35 bushels; the test weights 59, 59, and 58 pounds; and the smut percentages 0.2, 2.0, and 8.0, respectively. The copper carbonate was somewhat less effective in the case of the highest infection.

TABLE 36.—*Relative effects of seed treatment with formalin and copper carbonate upon the grain yield and test weight of Kanred winter wheat differing in amount of smut infection, 1924.*[a]

Nebraska Experiment Station.

	Crop harvested in 1924		
Treatment of seed planted	Smutted heads in field, %	Weight per bushel in pounds	Yield per acre in bushels
Nearly smut-free seed planted			
No treatment	0.5	59.8	35.1
Formalin	0.2	59.3	36.0
Copper carbonate	0.2	59.3	36.0
Seed planted containing 10% smut previous year			
No treatment	38.0	55.0	27.5
Formalin	1.0	59.0	33.1
Copper carbonate	2.0	59.0	34.0
Seed planted containing 20% smut previous year			
No treatment	63.0	52.8	20.6
Formalin	2.0	58.5	34.7
Copper carbonate	8.0	58.0	35.3

[a] From Nebraska Experiment Station Res. Bul. 31.

SUMMARY

The data available concerning crop quality indicate a positive relation to seeding practices. In view of the wide variation in growth conditions throughout the country, no specific recommendations as to seeding can be made which will fit all regions. However, it is apparent as a general principle in the case of cereal crops that those practices which lead to maximum average yields are also satisfactory from the standpoint of crop quality.

In the case of corn, in those regions where it is a full-season crop, seeding early during the normal planting season insures earlier maturity, lower moisture content, better keeping qualities, and higher viability if exposed to low freezing temperatures.

The relatively early seeding of all small grains commonly leads to higher test weight and low percentage of hull in the case of hulled crops. Delayed seeding of wheat tends to increase its percentage of protein which is a quality much sought by the milling trade. Its attainment by this means is accomplished, however, at too much sacrifice in yield to be justifiable.

Under climatic conditions represented by the State of Washington, where wheat may become infected through soil-borne smut spores, minimum smut infection may be attained by extremely early or late seeding, at the expense, however, of yield. A medium early date results in reasonably low percentage of smut and maximum yield of grain.

So far as quality of grain is concerned, the cereals may be planted at a rate conducive to highest acre yield. Within reasonable limits the grain quality is but little affected in important respects by variations in seeding rate.

In the case of forage crops, where fineness of stem adds to the palatability and reduction in waste when fed, it is desirable to seed thicker than necessary to get the maximum yield. Ordinarily the yield will not be reduced thereby and the forage will be finer and more leafy.

It appears that for silage purposes, corn may be advantageously spaced somewhat closer than for grain in order to get maximum tonnage of feed. Unduly heavy seeding, however, results in no gain in yield and produces silage relatively low in proportion of grain.

Practically no data are available concerning the relation of manner of planting to the quality of the crop. Practices designed to give maximum yield are satisfactory from the quality standpoint and are most efficient in farm practice.

The formalin and copper carbonate treatments of smut-infected seed wheat are efficient means in most of the country for increasing the yield, test weight, and freedom from smut. Treatment with copper carbonate containing about 20% metalic copper is especially to be recommended.

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7. THE INFLUENCE OF TIME OF CUTTING ON THE QUALITY OF CROPS[1]

A. C. ARNY[2]

In order to consider the subject in hand to advantage it is necessary to have in mind what takes place in plants as far as the assimilation of materials is concerned in different stages of development.

The results of work by Snyder (37)[3] show that during the first 50 days of growth the wheat plant takes up 86% of the nitrogen, 75% of the potassium, 80% of the phosphorus, and 70% of the silica that it will finally contain at maturity. The 50-day period extended to within 15 days of heading and to within 31 days of the milk stage in the development of the wheat plant.

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[1] Paper read as a part of the symposium on "Controlling the Quality of Crops" at the meeting of the Society held in Chicago, Ill., November 17, 1925.

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[3] Reference by number is to "Literature Cited," p. 701.

The greater portion of the necessary plant foods is taken up in the early stages of growth according to Adorjan (1), and are used as needed as the plant develops. When the plant is in flower, phosphorus is being taken up at a more rapid rate than nitrogen, but after that stage the assimilation of phosphorus ceases and nitrogen is taken up only as needed in seed formation.

Trowbridge, et al (43) confirmed these results for the wheat plant and showed that the development of timothy was similar to that of wheat. They call attention to a difference in the translocation of stored materials which in wheat is all toward the kernels but in timothy is in two directions, upward to the seed and downward to the bulb. This difference holds for all seed-producing perennial plants with storage organs.

It has been shown by the researches of Gericke (13) and others that applying nitrates to wheat at heading time results in a higher protein content of the grain. Swanson (40) concludes from his data that, although a large amount of nitrogen is absorbed from the soil by wheat plants in the early stages of growth, the time between heading and maturity is a critical period. High protein wheat is possible only if the supply of nitrogen in the soil and available to the plant during that period is ample and carbohydrate synthesis is not above normal.

Summarizing the results of the available data on the stage of development of the plant in relation to assimilation of plant foods, Bailey (2) states that mineral matter is absorbed from the soil by the developing wheat plant at a very rapid rate in the early stages of growth. By the time the plant is in flower practically enough has been assimilated to enable it to function normally to maturity by moving these substances to the places where they are needed. Throughout the period of kernel development nitrogen continues to be taken up from the soil but at a relatively slow rate.

Since there is a large translocation of assimilated materials from the leaves and stems to the grain or seed from flowering to maturity, it is evident that growers can exercise more influence over the quality of forage crops through time of cutting when the entire plant is utilized than is possible in crops harvested for the grain or seed alone. Therefore, these two groups of crops will be discussed separately.

The results of Kedzie (21) with wheat may be taken as representative of the early work in relation to the protein percentages in wheat at different stages of development. His results indicated that the percentage of protein decreased regularly as the wheat kernels became more mature. Finally, when the grain became over ripe, the percentage of starch decreased somewhat resulting in a slight increase in the protein percentage. Olson (31) shows a decrease in nitrogen percentage in the kernel of wheat sampled at weekly intervals from July 1 to July 29 with a regular increase in the total nitrogen and kernel weight.

Later researches of Brenchley and Hall (5), Thatcher (42), and Kiesselbach (22) with wheat and Harlan (18) with barley show that there is a tendency toward a reduction in the protein percentage in the kernels in the earlier stages of development and an increase during the latter part of the period. There is a regular increase in total protein and dry matter to maturity. The mature barley kernels in Harlan's investigations contained 42.8% moisture.

These differences in results are undoubtedly due largely to variations in the conditions under which the crops were grown.

Since some of the results have indicated that the percentage of protein decreased as maturity was approached, stage-of-cutting trials with the object in mind of securing grain with a higher percentage of that constituent have been carried out.

CROPS HARVESTED FOR GRAIN

The rapid increase in the extent of merchandising wheat used in the manufacture of bread on the basis of protein content indicates the importance of this constituent. Freedom from serious frost injury and weathering indicate sound wheat. Good weight per bushel indicates high flour yield.

Freedom from damage and weight per bushel are indications of quality in the feed grains.

Samples were gathered daily by Briggs (6), presumably with the entire length of straw attached, from the time the grain was in the milk to the time it was fully ripe, and spread to dry in a well-ventilated building. Until the grain reached the medium dough to stiff dough there was an increase in kernel weight but after that very little increase was seen. Making due allowance for fluctuations, it appears that after the milk stage the percentages of protein remained approximately the same until maturity.

McDowell (28) harvested samples of wheat at four stages, *viz.*, milky, dough, yellow ripe, and dead ripe. At each stage (a) a portion of the kernels was removed from the spikes immediately, (b) left in the spike to ripen, no straw attached, (c) ripened in the straw, and

(d) ripened with the roots from which the soil had been removed standing in water. The material was kept in the laboratory after harvest. The kernel weights increased up to the yellow-ripe stage. For the milky stage there was a decided increase in kernel weight for the portion with the roots standing in water. In the other instances there are indications that the kernels derived some benefit from the straw, but the differences are slight and probably within the limits of experimental error.

The results secured from harvesting five varieties of wheat and four varieties of oats at (a) the green-neck, (b) yellow-neck, and (c) mature stages are reported by Dunham (8). For the green-neck stage spikes and panicles were selected in the stage where the glumes of the top kernels had turned yellow and the straw of the neck (portion immediately below spike or panicle) was still green. The straw immediately below the spikes or panicles had turned in the yellow-neck stage, but the straw below was still somewhat green. The plants were hung in a well-ventilated room to dry. After threshing, equal numbers of kernels were weighed and comparisons were made. As an average for all varieties there was an increase of 15.7% for the wheat and 25% in weight for the oats in favor of harvesting at maturity rather than at the green-neck stage. An average increase in weight of 13.9% for the wheat and 24.5% for the oats was secured in favor of the yellow- over the green-neck stage. The next year Dunham (9) secured practically the same results from cuttings made at the same stages with the binder and the grain cured in shocks.

In the work reported by Saunders (33) spikes previously marked were harvested at three-day intervals from July 21, when the kernels upon drying were very small and shriveled, until August 15 when the grain was ripe. At each date part was left (a) with 3 inches of straw attached, (b) with half length straw attached, (c) with full length straw attached, and (d) with full length straw and roots attached. The samples were hung in a warm, well-ventilated loft to dry. Due to the rapid drying out of the straw practically no transfer of material from the straw to the grain was possible. Therefore, the weights per 1,000 kernels for the four methods of harvest at each date were averaged.

The kernel weight increased up to August 8. The percentage of protein decreased from July 21 to August 30 and then increased slightly. There was a regular increase in the amount of protein per 1,000 kernels to August 6, then the amounts remained practically uniform to maturity. From the results the author concludes that in an ordinary summer slight loss in yield or quality would result in eastern Canada from harvesting wheat a week early. In parts of Canada where the summers are cooler than at Ottawa, the harvesting would probably be done at a still earlier date, probably two weeks earlier. Mention is also made of the fact that in portions of Canada where the summers are short harvesting early is the common practice.

The observation of Olson (31) that filling of the kernels ceases when the moisture content of the kernels is reduced to approximately 40% probably explains the failure of translocation of material to take place from straw to grain in these trials where the material was dried out with comparative rapidity.

Several workers have reported results from stage-of-cutting experiments where the grain was cured in the shock where drying out would be more gradual.

At Ottawa, Bedford (3) harvested wheat at four stages, *viz.*, (a) early milk, (b) late milk, (c) dough, and (d) ripe. The average results for a two-year period show no increase in yield for the wheat harvested at maturity over that harvested a week early at the dough stage. There was an increase in weight per bushel.

Harvesting wheat in the hard dough stage and curing it in the shock as compared with leaving it stand until ready for the header did not bring about any improvement in the physical appearance or protein content of the kernels, according to the work of Shaw (35).

Shutt (36) gives results for wheat harvested at two- to three-day intervals and permitted to cure in three ways, *viz.*, (a) kernels removed from spikes at once, (b) spikes with 6 inches of straw attached, and (c) spikes with all straw attached. The kernels for methods a and b were dried out under room conditions, and for method c the curing was allowed to proceed in the shock under field conditions. Due to dry conditions the wheat ripened sooner than usual.

The weight per 1,000 kernels where the wheat was cured in the shock averaged higher than for the other two down to July 17, and from then on the weights were practically the same for the three series. There was a regular increase in weight per 1,000 kernels to July 8 in each of the three series and after that increase was slight.

The percentages of protein for each of the three series decreased slightly and then increased up to July 8, after which the change was slight. There was less fluctuation in the protein percentage in series b cured in the shock than in the other two series. The amount of protein per 1,000 kernels increased rapidly to July 8, and from then on the increases were slight but consistent.

Results are given by Kiesselbach (22) for Turkey red wheat harvested at three stages of maturity, *viz.*, (a) early dough, (b) late dough, and (c) ripe for a five-year period. The data are from duplicate field plats and the grain was cured in the shock.

In another experiment 10 systematically distributed quadrats of the same variety of wheat were harvested at the following stages: (a) Milk, (b) early dough, (c) medium dough, (d) stiff dough, and (e) ripe. The grain was cured in shocks in the field. These stages vary from two to four days apart.

In the first experiment there is little change in the protein percentage from early dough to maturity. However, there is a decided increase in yield and weight per bushel from the early dough to the late dough stage and slight increases thereafter.

In the second experiment the increase in yield in the three-day period between the stiff dough and ripe stages is only 1 bushel, while between the medium and stiff dough stages the difference is 2 bushels. The 1,000-kernel weight for the stiff dough and ripe stages is practically equal.

Grain attacked by black stem rust is cut off more or less completely from its moisture and food supplies. Frequently such grain has been harvested considerably on the green side with the expectation of securing increased yields of better quality grain.

Ellis (10) harvested wheat badly infested with black stem rust at three-day intervals beginning at the late milk stage. The grain was cured in shocks in the ordinary manner. Cutting in the late milk stage resulted in grain weighing 56 pounds per bushel, while that cut at the stage where the grain was firm as determined by not being able to crush it between the thumb and finger weighed 59 pounds per bushel. The highest yields were also secured from the wheat cut in the "firm" stage. The conclusion is that rusted wheat should not be cut earlier than grain not attacked by rust.

The results from two cuttings of wheat affected with black stem rust to the extent of 75 to 80% are given by Stoa (39). The first cutting was made when the spikes were beginning to change color and the kernels were in the dough stage. The second cutting was made five days later when the crop was mature. The sheaves were shocked out of doors. The grain from the cutting made when mature had the advantage in yield per acre, test weight per bushel, weight per 1,000 kernels, and protein percentage, but the differences were not significant. In loaf volume and color the flour from the grain harvested at maturity was somewhat superior.

Baking tests were made of wheat cut at soft dough, hard dough, and maturity by Guthrie and Norris (15). Cutting at the hard dough stage did not result in smaller loaf volume.

Three-year average yields and weights per bushel are given by Kiesselbach (25) for oats harvested at two-day intervals, beginning six days before maturity. The oats was considered mature when three-fourths of the panicles appeared fully ripe. Harvesting four days early did not lower the yield but resulted in a decrease in the weight per bushel.

The practice of cutting flax before maturity is not as general as that of cutting grain early. Ivanow (20), working in Russia, found that in the two weeks following flowering the seeds contain little oil. In the next two weeks the oil percentage increases rapidly and during the last two to three weeks the oil is deposited in the seed slowly. There was an increase of 3.4% in oil content between the stage "seeds unripe but bolls somewhat dry" to the stage "seeds ripe."

Eyre and Fischer (11) harvested flax at four stages of development. An increase of 7.95% in oil content occurred between the time when the seeds began to turn brown and the time when they were full grown but not loose in the capsule. A further increase of 2.85% in oil content occurred to the time when the seeds were loose in the capsule. The results in both instances were secured from seed removed from the straw in the stage mentioned and the determinations made immediately.

The data indicate that under cool weather conditions grain crops may be harvested and shocked a week before maturity, and under warm, dry conditions from three to four days before maturity with practically no reduction in yield or quality. This information is of considerable practical importance to growers of large acreages of grain in humid sections. Except as an aid in avoiding damage by frost, there appears to be no advantage in following regularly the practice of early cutting with the expectation of securing improved quality in grain crops. However, under conditions where cool weather prevails after flowering and there is an abundance of water in the soil, harvesting approximately a week early should aid in limiting the elaboration of an over-abundance of carbohydrate and result in a wheat of somewhat higher protein content. Where the straw of a grain crop is to be fed, harvesting before complete maturity aids in preventing leaching of nutrient materials from the leaves by dew and rain. It appears that harvesting flax before the seeds are loose in the boll results in a lower percentage of oil.

FORAGE CROPS

Composition, digestibility, and palatability are of major importance in forage crops. Necessarily, they must be considered along with yield and the class of animals to which the crop is to be fed. Percentage leafiness and color are indications of quality. Maintenance of stand of perennial forage crops is necessary in order that satisfactory yields may be secured over the desired length of time. Time of harvest in relation to weather conditions may influence both composition and palatability.

That appreciable losses do occur due to leaching by rain and dew has been demonstrated by LeClerc and Brezeale (26). A loss of 18 pounds of protein per acre in timothy harvested at maturity as compared with that harvested in the dough stage is reported by Trowbridge, Haigh, and Moulton (43). Decrease in weight of dry matter per acre through loss of leaves as the plant advances in development occurs to a limited extent in grass plants and to a very much greater extent in leguminous crops. Data will be given on this point in the discussion of leguminous crops.

SILAGE CROPS

That protein is considered in connection with silage is evidenced by the practice of planting soybeans with the corn in order to raise the percentage of that constituent. There is some evidence that increases in protein content brought about in this way are too small to affect the balancing of the ration to the extent credited. In this way more harm than good may result. Total yield of digestible nutrients, together with palatability and succulence, are the important considerations. It appears to be fairly well settled that the most vigorous strains of the varieties best suited for grain production give better results than the so-called "silage corns" which grow tall, mature late, and produce lower amounts per acre of the valuable feed constituents.

This viewpoint is supported by the work of Hayden and Perkins (19). Cutting when the kernels have dented and the leaves are very largely still green gives the highest yields of the most valuable silage. At this stage the moisture content is about right to secure satisfactory packing and preservation. It appears from the work of Schoth (34) that the best stage to cut sunflowers, both from the yield and palatability standpoints, is when the seeds are from three-fourths to fully ripe. The addition of 5 pounds of salt per ton of silage apparently increased the palatability.

HAY CROPS

Grass hays at best have a medium protein content and probably from that standpoint merit special care in harvesting and curing in order to save what little there is.

The work of Waters (44) and of his co-workers, Trowbridge, Haigh, and Moulton (43), shows the yield of dry matter per acre in timothy hay to be within 4 to 5% as high at full bloom as at any of the later stages of development and higher than at any earlier stage of development.

The coefficients of digestibility for (a) total dry matter, (b) crude protein, (c) crude fiber, and (d) ash and nitrogen-free extract are higher at full bloom than at any later stage of maturity. With the total digestible nutrients per acre in the dry matter of the hay at full bloom taken as 100, at the stages of seed formed, seed in dough, and seed fully ripe, the rank was 93.7, 87.9, and 81.6, respectively.

In the palatability trials, steers and dairy cows showed a decided preference for the hay cut at the partly in bloom and the full bloom stages, while sheep showed no preference.

There was a regular increase in the dry matter percentage in the green hay from full bloom to the time the crop was mature. At full bloom the moisture content of the green hay was 65.54%, and at the time the seed was ripe the moisture percentage was 43.03%. This makes the curing of timothy hay at the full bloom stage somewhat more difficult than at later stages of development under the same conditions for curing. Usually conditions for curing are less favorable at the time the timothy is in full bloom than later.

Although the cuttings were made on a new area each year, the areas harvested at different stages the previous year were kept under observation. The conclusion was that cutting before bloom and at full bloom resulted in a reduction in the stand by preventing adequate storage of reserve materials in the bulbs.

That the cutting of timothy hay at full bloom or earlier is less injurious in the eastern sections of the United States than in Missouri is explained by Waters as follows: (a) Eastern farmers grow timothy and clover together in short rotations. The first year the crop is largely clover and the second year largely timothy. Thus timothy follows clover in the rotation and has the favored place and the next year the stand is plowed up. (b) The rainfall is heavier and permits a heavier second growth than is produced in the corn belt. The second crop of hay stands long enough to store reserve material in the roots in sufficient amounts to make the growth vigorous the following spring.

The highest yields of weed-free hay were secured by Wiggans (46) by cutting timothy in full bloom and the next to the highest by cutting before bloom. Cutting in the dough and ripe stages resulted in reductions in stands of 15 and 10%, respectively, in four seasons. This work was carried out on plats set aside for this purpose for a period of years and hence the results were cumulative. In these tests early cutting controlled the weeds, daisies in particular, more effectively than harvesting at later stages and thus lessened weed competition. Wiggans considers elimination of competition by weeds, a fair stage of fertility, and the development of a good aftermath more important in maintaining vigorous stands of timothy in northeastern United States than time of cutting in relation to bulb formation.

As far as yield of digestible nutrients is concerned, it appears desirable to cut timothy hay not later than the full bloom stage. Where cutting at this stage as a regular practice thins the stand materially so that serious reductions in yields occur, some sacrifice in quality of hay must be made in the interest of keeping the fields in a productive condition.

The highest yields of hay on the 15% moisture basis were secured from Black amber sorghum and Sudan grass when they had reached the soft dough stage, as reported by Kiesselbach (23). While the crude protein percentage was not the highest at this stage of development, it was only slightly lower than at full heading and significantly higher than at maturity. There was an increase in nitrogen-free extract from the hard dough stage to maturity.

Leguminous crops are usually grown as a relatively cheap source of protein in a ration when used with other feeds high in carbohydrates. Hence, both high protein content and total yield of protein per acre are the most desired qualities in leguminous hays. Second only to high protein content, high yield of digestible nutrients per acre for legume hays indicates quality. Bright green color and leafiness indicate the qualities that have been mentioned.

The highest yields of soybean hay on a dry matter basis were secured by Willard (47) between the stage beans well formed and the stage leaves one-fourth yellow. The percentage of leaves decreased from 66 at middle bloom to 37 at the stage leaves one-fourth yellow. This was not due to loss of leaves but to the increasing percentages of pods and seeds. At this stage the yield of leaves had lowered and that of seed had gained over the yields secured at the stages beans well formed and beans half grown.

Attention is called to the difficulty of curing soybean hay at the stage when one-fourth of the leaves are yellow and the seed have developed to from three-fourths to full size. The best time to cut soybeans for hay appears to be from the time the beans are well formed to the time they are half grown. This is before the leaves have begun to turn to any considerable extent.

Seed yields increased to maturity. The germination of the beans harvested before they were half grown was as high as for the beans harvested at more mature stages.

It appears that weather conditions might have a very considerable influence on the way the beans would cure. Especially in the less humid sections, it might be entirely practical to secure high quality hay by cutting the beans at the stage when one-fourth of the leaves had turned yellow if that was found to be the preferable stage as far as other considerations were concerned.

The work of Snyder and Hummel (38) shows the protein content of alfalfa as well as the percentage of leaves to be highest in the beginning bloom stage, and considering everything, they recommended cutting when one-third of the blossoms have appeared, in order to secure the largest amounts of the several nutrients in the most valuable forms.

Widstoe (45) studied the chemical development of alfalfa from the time it reached a height of 6½ inches on May 4 to maturity on August 24. In the first crop there was a decrease of leaves from 43.86% atbeginning bloom to 25.26% at full flower. The crude protein in the leaves averaged approximately two and one-half times that in the stems. In the leaves and in the whole plant there was a decrease of approximately 5% in the protein from beginning bloom to full flower. The percentage crude fiber in the whole plant increased from 28.07 at beginning bloom to 36.77 at full flower. Differences in the second crop approximated those in the first crop.

In a very recent publication Salmon, Swanson, and McCampbell (32) make available valuable data on the time of cutting alfalfa, covering a period of eight years.

These data on the composition of composite samples representing crops cut at bud, tenth bloom, full bloom, and seed stage emphasize the high feeding value of the leaves as compared with the stems. The leaves averaged over twice as high in percentage of crude protein as the stems from cuttings made at the same stages of development. The leaves were higher in ash, nitrogen-free extract, and ether-extract content than the stems. On the other hand, the crude fiber content of the leaves in percentage averaged less than half of that in the stems from cuttings made at the same stages of development. This emphasizes the great importance of saving the leaves in the making of alfalfa hay.

The average percentage of leaves for the cuttings made at the bud stage was 53.4; tenth bloom, 51.1; full bloom, 48.4; and seed stage, 41.6. The greatest difference in leaf percentage was in the first cutting where it was 49 for the bud stage, 47 for tenth bloom, 43 for full bloom, and 38 for seed stage. There was a calculated loss of leaves in harvesting averaging for all cuttings for the seven-year period 19.1% for the bud stage, 14.5% for the tenth bloom, 20.4% for full bloom, and 22.2% for the seed stage.

As far as the desirable feed constituents are concerned, and percentage of leaves as well, the evidence appears to be very clear that cutting before full bloom is the desirable practice. The evidence from the analytical data is supported by feeding tests with steers. From feeding tests carried out over a period of three winters it was found that the amounts of feed necessary to produce 100 pounds of gain in steers was as follows: Bud stage, 1,628; tenth bloom, 2,086; full bloom, 2,163; and seed stage, 3,910. The tenth bloom hay used the second winter was of a poor quality and it is doubtful if the results for that year should be averaged in with those from the other two. From the results they conclude that, "The general opinion that the feeding value of alfalfa hay for cattle decreases with delayed cutting is supported by these data." For work horses, McCampbell (27) states that alfalfa cut when it has reached full bloom is preferable to that cut at earlier stages. No work appears to be available along this line with sheep, but in all probability they would show no preference as far as palatability is concerned.

Alfalfa cut (a) just before bloom, (b) in early bud, and (c) in late bloom, under the direction of Foster and Merrill (12), yielded 5.34, 4.91, and 4.55 tons per acre as an average for five years and produced 705.6, 561.9, and 490.5 pounds of beef per acre, respectively.

For dairy and beef cattle, alfalfa hay cut before full bloom is preferable to that cut at full bloom or later. For horses, hay cut at full bloom is desirable.

There remains, then, to consider the yields secured from cutting at the various stages and the effect on the stand where it is desired to grow alfalfa on the same fields for a period of several years.

From the work of Salmon, Swanson, and McCampbell (32) average yields of grass-free alfalfa were as follows: Bud stage, 2.65 tons per acre; tenth bloom, 3.21 tons; full bloom, 3.43 tons; and seed stage, 2.91 tons. In considering these yields, it should be noted that in 1921 the yield at tenth bloom was lower than the others due to insect injury which occurred on this stage because it happened to be developed to the point where it was most attractive when the insects happened along. The cuttings made at the bud stage yielded at a significantly lower rate than the cuttings made at tenth and full bloom. The average yield for the tenth bloom stage is somewhat lower than for the full bloom stage, but the difference is not significant. It is remarkable that under this extremely severe cutting treatment of from five to six cuttings each season over a period of 8 years, the yields from the bud stage averaged so near that of the cuttings made at the more advanced stages.

Calculating the average yields per acre into average yields of beef produced per acre, the following results are secured: Bud stage, 322 pounds; tenth bloom, 308 pounds; full bloom, 317 pounds; and seed stage, 147 pounds. This indicates that the cuttings at the bud stage, although significantly lower in yield than those from tenth and full bloom, were fully as satisfactory as the others as far as gains per acre with cattle are concerned.

Feeding trials with the alfalfa cut at the four stages of development were made with steers over a three-year period. As an average for the three-year period the number of pounds of feed required to produce 100 pounds of gain was found to be as follows: Bud stage, 1,628; tenth bloom, 2,086; full bloom, 2,163; and seed stage, 3,910.

The point is emphasized that cutting in the bud stage particularly, and to a lesser extent in the tenth bloom stage, stimulates growth. "Thus it may be pointed out that in the first year of the experiment before the plants were weakened by too frequent cutting, the highest yields were secured from the plots that were cut the most often. The plants in the bud stage made the greatest linear growth."

Nelson (30) reports results that show the opposite results. His determinations show a slower subsequent growth for the plants cut at the early bud stage as compared to that from plants in full bloom and a falling off in successive yields during the first season. Variations in the stage of development of the plants cut and age may account for these differences.

The highest yields per acre for one season on a well-established alfalfa field were secured by Moses (29) from cuttings made in the tenth bloom and bud stages and from varied cuttings. Cutting the first two crops in the bud stage and the subsequent ones in full bloom gave 6,178 pounds of clear alfalfa hay as compared with 5,229 pounds for the full bloom stage. Making the first cutting in the bud stage, the second in tenth bloom, and the last two in full bloom gave a yield of 6,244 pounds of hay per acre. At the Minnesota station the results of two years of work indicate that the varied method of cutting as suggested by Salmon gives satisfactory results.

Yields of 4.0 tons for full bloom, 3.2 tons for tenth bloom, and 2.5 tons for bud stage are reported by Graber (14). Besides larger yields, greater permanency of stands, more favorable weather conditions at cutting time for cutting, and less competition with other work are urged in favor of the two-cutting system. Recognition is given to the fact that alfalfa hay cut in the full bloom stage is of a coarser quality than that obtained from earlier cuttings and, where soils produce exceedingly rank growth and lodging occurs, it may be advisable to cut the first crop somewhat earlier in order to secure good quality hay.

From cuttings made at the normal time which was between tenth and quarter bloom, Kiesselbach (24) secured 5.57 tons of alfalfa hay as compared with 3.70 tons for earlier than normal and 3.47 tons for later than normal. The fourth year all plats were cut at the normal time in order to determine the residual effects. The results were as follows: Normal, 3.4; earlier than normal, 3.2; and later than normal, 3.1 tons. As an average for the four-year period, cutting at normal time gave the highest yields.

Hansen (16), at the Tystofte Experiment Station in Denmark with a yearly precipitation varying from 14.88 to 24.09 inches over the five-year period during which the work was done, found that three cuttings per season made at the stage of development when the blossoming had well started was the most profitable under favorable conditions for alfalfa growing. Cutting three times per season at this stage of development gave the highest yields, the plants were not weakened and the field was easy to keep clean. It was still easier to keep fields cut twice in full bloom clean, but this advantage was counterbalanced by a somewhat lower yield and a considerable lowering of the quality of the crop.

On the island of Bornholm, Hansen (17) secured results over the four-year period (1908–11) which showed slightly higher yields for two than for three cuttings per season, but the quality of the hay was inferior.

In Minnesota as high yields have been secured from cuttings made at from one-tenth to one-fourth bloom as from later stages and the quality of the hay has been superior in the majority of cases.

When yield of hay is considered by itself, there is a fair agreement of the results secured in the different locations. Over a period of from three to four years it is clearly in favor of cutting from the beginning of bloom up to one-fourth to one-half in bloom. The

Wisconsin data appear to be an exception to the results secured at other locations. For a period of a year or two where permanency of stand is not an important consideration cutting at the bud stage might well be followed as far as yield is concerned.

From the work of Salmon, Swanson, and McCampbell (32) the very severe treatment of cutting alfalfa in the bud stage from five to six times per season over a period of eight years brought about a considerable lowering of the stand some time during the second year accompanied by a decrease in the vigor of the remaining plants. At the same time very decided reductions in stands took place in the plats cut at tenth bloom, full bloom, and the seed stage. The seventh year the plats cut at the hard bud stage had a stand of 26.7 plants per square yard as compared with 32.8 for the full bloom stage and 41.8 for the seed stage. This shows a remarkable survival of plants for the bud stage cutting under the severe treatment carried out over so long a period. There was an encroachment of grasses during the second year. The stands of the plats cut in tenth bloom were equal to those of the later cuttings up to and including the sixth year when circumstances outside of the experiment brought about a thinning.

Considering all factors the authors conclude as follows, "It is doubtful if any farmer can afford to cut continuously or even generally earlier than tenth bloom in fields on which it is desired to maintain alfalfa. On the other hand, it is doubtful if the difference in yield in favor of full bloom cutting is sufficient to justify delaying the beginning of cutting until that stage of growth is reached especially in view of the poorer quality of the hay and a lower yield if cutting is unexpectedly delayed by bad weather or other factors."

A very marked reduction in stand of plants was found by Moses (29) to occur in the alfalfa cut every 10 and 20 days throughout one season and some reduction in stand occurred in the alfalfa cut at all of the other stages from bud up to tenth bloom. Very little loss occurred in the seed stage plats. With the exception of that for the seed stage, differences in loss of stand between any two methods of cutting were not significant.

He also found that grasses invade stands of alfalfa regardless of the stage of cutting. The encroachment of grasses on the plats cut every 10 and 20 days was less than on those cut in the bud stage throughout the season or on the plats where the first cuttings were made at the bud stage and the later cuttings made at tenth or full bloom. He suggests that cutting alfalfa at the bud stage, besides reducing the stand and weakening the plants that remain, gives the annual grasses in particular an equal chance with the alfalfa at a time when conditions favor the growth of grasses. Alfalfa that is not cut before tenth, full bloom, or seed stages competes with the grasses both by shading and crowding. This view appears to be substantiated by unpublished data from the Minnesota station.

Nelson (30) found a very marked reduction in the stand on plats cut at early bud stage as compared with cutting at full bloom during the first season. Lack of adequate drainage may account for this difference as compared with the Kansas results. In Minnesota no greater reduction in stand has taken place on plats cut in the hard bud stage than in other plats cut at tenth or full bloom during the first, second, or third year.

Hansen (16 and 17) found that cutting vigorous alfalfa three times per season when bloom had well started did not weaken the stand. The vigor of the plants was maintained over a period of years and the fields were easy to keep clean. Stands that were less strong increased in vigor when cut twice each season or alternately twice one season and three times the next.

There appears to be a fair agreement as to the relation between stage of cutting of alfalfa and maintenance of satisfactory stands. It is evident that there is considerable latitude in time of cutting that will maintain satisfactory stands provided always that when the reserves in the roots are drawn on heavily at one time they are permitted to be restored in the next or succeeding cuttings. Cutting vigorous alfalfa three times per year where the growing season is sufficiently long to permit appears to maintain the alfalfa in a vigorous condition over a period of years.

Where the winters are severe a growth of 6 to 8 inches in height in the fall for winter protection appears to be an important consideration in maintaining stands.

SUMMARY

The time at which or the period during which grain and forage crops may be cut with most satisfactory results depends on a considerable number of factors which must be considered together. Chief among these are yield, quality, weather conditions at harvest time, conveniences in relation to other work, and the maintenance of satisfactory stands of perennial crops. Differences in climatic and soil conditions influence the results secured in various locations.

Harvesting crops grown primarily for their grain or seed before they have reached approximately full maturity does not improve the quality of the product. It is of considerable practical importance to know that these crops may under cool, humid conditions be harvested a week or more before maturity, and under warm, dry conditions three to four days early without appreciable loss in yield or quality.

Where the straw of a grain crop is to be fed, harvesting before maturity aids in preventing leaching of nutrient materials from the straw.

The composition, digestibility, and palatability of forage crops can be directly controlled by cutting at the stage of maturity giving the desired results.

Considering composition, digestibility, and palatability in connection with yield and maintaining a satisfactory stand, the best time to cut grass hays, such as timothy, appears to be at the time of full flower or just past that stage. Letting the crop stand beyond that stage results in a deterioration in quality without a compensating increase in yield. The evidence indicates that the annual grass crops should be permitted to develop the kernels to the soft dough stage in order to secure the best balance between yield and quality of hay.

It appears desirable to cut the soybean crop for hay somewhere between the stages "seeds well formed" and "beans half grown." Delaying harvest beyond the latter stage results in lower quality of the product and greater difficulty in curing it properly, particularly under humid conditions.

Making all of the cuttings of alfalfa in the bud stage over a period of years results in lower yields of high quality hay. The lower yields result from a thinning of the stands and a weakening of the remaining plants. When it is desired to maintain stands over a period of years, this practice is not to be recommended. However, the evidence is that, with some exceptions due to climatic and soil conditions, an occasional cutting or the first cutting every year may be made at this stage without lowering the yield or injuring the stand. This knowledge is of considerable value to those who grow alfalfa in short rotations where maintaining stands for a period of years is not a consideration; when the first crop grows so rank that it lodges before the usual stage of cutting is reached: and in seed-growing sections where cutting the first crop at full bloom results in a late-maturing seed crop which is apt to be injured by frost.

Exceptional soil conditions, weather conditions at harvest, and convenience in relation to other work separately or combined may make cutting at full bloom with approximately the same yields and a lower quality of hay the most desirable program. However, the evidence indicates that ordinarily cutting somewhere between tenth and half bloom as a regular practice results in the best balance between yield on one hand and quality on the other and at the same time maintains the stand in a vigorous condition. Leaving a growth of from 6 to 8 inches high in the fall to hold the winter snows appears to be an important consideration in maintaining stands under severe winter conditions.

The suggestion is made that in future investigations of this nature the crops be cut at definite stages of development and that care be taken to describe in detail the one or more characters or characteristics that indicate each of the stages at which cuttings were made. This facilitates the comparison of one piece of work with another. Good photographs are a distinct aid.

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MATHEMATICS AND AGRONOMY[1]

"STUDENT"

The nature of pure mathematics is such that the conclusions follow inevitably from the premises and may be said to be contained in them. Consequently, if in applying mathematics to affairs we reach absurd conclusions, we may be sure either that a blunder has been made or that in some essential point the data of the mathematical problem did not correspond to the facts.

For it must be remembered that mathematical analysis deals with abstractions and that commonly the abstractions chosen are very much more simple than the facts, either in order to secure a generalised result, or because the analysis would otherwise become too difficult.

Thus, even in the ordinary text book problem we may have to deal with weightless ropes or frictionless pulleys, with basins which empty through the waste at a uniform speed regardless of the depth, or bricklayers who work at the same rate, however closely they may be crowded together.

GENERAL CONSIDERATIONS

It may be assumed then that if mathematical analysis applied to the interpretations of agronomic experiments has given absurd or inconsistent results, it is probably because the facts were not correctly represented by the abstractions with which the mathematics dealt. It may, therefore, be worth while to consider what limitations are imposed by the imperfect correspondence between the conditions of our experiments and the mathematical abstractions from which are constructed the tables which are used to interpret their results. It may also be possible to find means of designing experiments so that they may be interpreted with as little error as possible.

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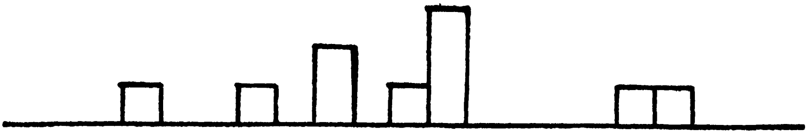
I shall begin by setting out, as far as may be, in non-mathematical language, the reasons which lead us to use certain tables in interpreting our experiments, and then examine the conditions under which we are justified in doing so. But however much it may be desired to avoid mathematical language, it is necessary to define a certain number of terms accurately, and in what follows the following words will be used in the sense given below:

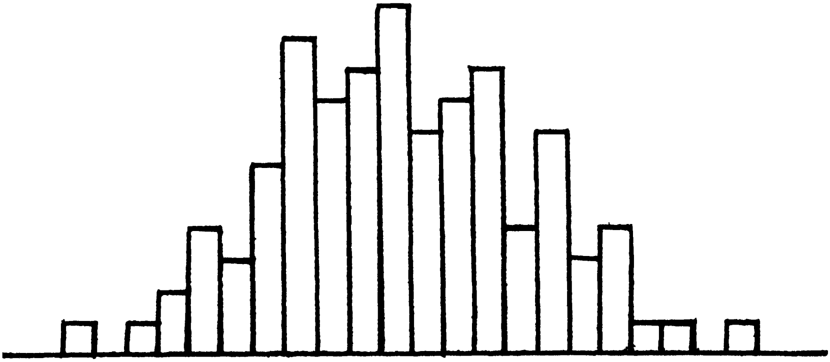
1. *Variable.*—A quantity that can present more than one numerical value, e.g., height, birthrate, the yield of a plat.
2. *Variate.*—An individual value of a variable, e.g., 5 ft. 10 in.; 19.63 per 1,000, 19½ lbs.
3. *Population.*—All the individuals under discussion. It should be noted that all these individuals need not exist. We may be dealing with a population of all individuals which could have existed under certain conditions. A population may, and generally does, vary in more than one character. It is necessary to be quite sure exactly what is the population with which we are dealing, and to remember that our conclusions cannot necessarily be extended to other populations. If, for example, we have a series of plats from which we deduce that one variety of oats will give a higher yield than a second, and all the experiments were carried out in an exceptionally dry summer, our population would be "comparisons of yields in an exceptionally dry summer," and without further work it is obviously impossible to draw general conclusions applicable to comparisons of yields in all summers.
4. *Sample.*—A number of individuals selected to represent a population.
5. *Random Sample.*—A sample selected in such a way that any individual in the population has an equal chance of being included in the sample. It is always difficult, and often impossible, to discover anything definite about a population from a sample which is not random.
6. *Frequency.*—The number of variates occurring between any limiting values of a variable.

Clearly, it is possible to give a geometrical representation of the frequencies occurring in any sample by setting out the scale of its variable horizontally along a base line and measuring vertically the frequency on each unit of the scale. This gives the familiar figure consisting of columns of equal width but of unequal height which is known as a a histogram.

If the sample is small we may have such a figure as this:



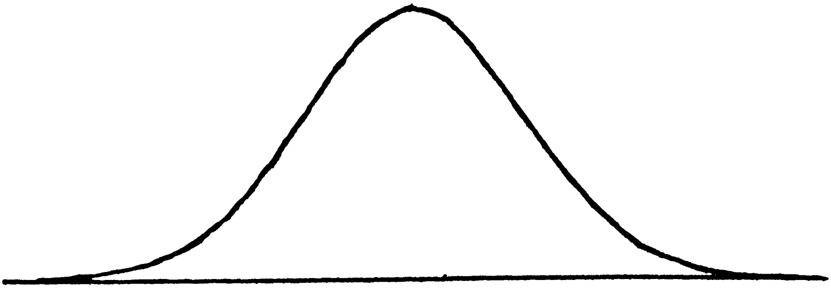
Each square represents one variate; but if the sample is larger, it will take a more continuous form, such as this:



As the numbers increase, the tendency is for the outline to become more and more regular.

It should be noted that in practical affairs, the columns of the histogram must necessarily have a definite width, that of the unit of measurement, this must be at least the width of the smallest measureable unit of the variable and is usually much wider. Thus, although weight can be measured in fractions of a gram, the yields of plats are given to the nearest pound or cental.

Nevertheless, we can imagine that if the unit of measurement were to be decreased indefinitely and the sample increased without limit so as to become an infinitely large population, the histogram with its irregular steps would be replaced by the smooth continuous curve which is known as a frequency curve. These frequency curves are necessarily abstractions; nobody ever reached one by plotting out the frequency of a sample, but it is often comparatively easy by following the instructions of mathematicians who have studied the subject to find the equation and draw the graph of a frequency curve which describes a population such that a given sample might have been drawn from it by random selection. While frequency curves are of many types, the only one to which attention need here be drawn is that discovered by Gauss and La Place, and known variously by their names and as the "Probability Curve" or "Normal Curve of Error." This curve was reached by supposing that the error of an observation is the sum total of an infinite number of infinitely small components each of which may be either positive or negative, and it purports to give the frequency with which errors of any given magnitude occur. The following properties are of interest:



1. It is symmetrical about a middle vertical line—the mean.

2. The curve is completely determined if we know the total frequency which it represents, i.e., the area between the curve and the base line, the mean, and either (a) the average of the squares of the distances of the errors from the mean, the mean square of error—called by R. A. Fisher the Variance—or (b) the average distance of the errors from the mean—the mean error.[2]

3. The square root of the mean square of error is called the "Standard Error" or "the Standard Deviation," S. D.

4. 0.6745 times the Standard Deviation is called The "Probable Error," and is such that *in this special type of curve* one-half of the errors lie within a distance of once the probable error on either side of the mean. It should be noted that apart from this normal curve of error, the probable error has no exact meaning.

5. Tables giving the area of the curve lying between any given

[2] In view of the fact that some American writers have stated that it does not much matter whether the probable error be calculated from the mean square (Bessel's formula) or the mean error (Peter's formula), it may be as well to state categorically that it does matter. R. A. Fisher (*In* Monthly Notices, Roy. Astron. Soc., June, 1920) has shown that the latter method is equivalent to wasting 12% of the observations, since 100 cases treated by the first give as accurate a measure of the probable error as 114 cases treated by the second.

error, x, and either the mean or $-\infty$ have been constructed. In these "x" is measured either in terms of the Standard Deviation or of the "Modulus" c (c = the S. D. x $\sqrt{2}$) and the area as the fraction of the total area of the curve.

Since an unknown observation may fall with equal probability in any equal area of the curve, these tables can be used to calculate the odds against an observation falling beyond any required distance from the mean.

6. Many naturally occurring populations may be described very closely by a normal curve of frequency, and can then be determined by the total frequency, the mean, and the S. D.

7. Although many populations exist which cannot be described by this curve, the samples which we are able to obtain in agronomic work are generally too small for us to be sure that the population they represent is not normal.

8. Even in the case of samples drawn from a population admittedly not normal, the *means* of such samples belong to a population (of means) which becomes more and more nearly normal the larger the samples.

It is, therefore, usual to assume, and *in the case of large samples* the assumption can be made without appreciable error, that the published tables of the normal curve can be used to calculate the odds against the mean of the sample differing by more than any required amount from the mean of the population.

It should here be remarked that in order to be able to use the tables in this way there must be a unit of measurement of the variation (S. D., Probable Error, or Modulus of Error), and there are two ways in which this can be arrived at.

The first way is that used by astronomers, routine analysts, and such people as can repeat observations many times in a standard manner. Working in this way, they can find a value of the S. D. from some hundreds of determinations of the same quantity, and they can then use this figure for smaller numbers of determinations in subsequent experiments.

The second way is more usual. It is to calculate the S. D. of the sample and use this value instead of the S. D. of the population. This has the advantage that at all events there can be no possibility of using the Standard Deviation of the wrong population, which, conceivably, might otherwise happen. But, on the other hand, very few series of experiments are sufficiently long to allow of an exact estimate of the Standard Deviation being made.

For the Standard Deviation determined from a sample is just as much subject to error as is the mean, and consequently, if "x" is to be measured in terms of the Standard Deviation of the sample, the uncertainty of the conclusion is necessarily increased. Further, it does not follow that the frequency curve of means of samples when measured in this new unit, which is different for each sample, will any longer be found to approximate to the "normal" curve. In fact, it has been shown *not* to do so for small samples, and Student's tables[3] have been constructed to meet the particular case of small samples drawn from a population which is itself normally distributed.

This survey of the foundations on which the application of probability to affairs are based has doubtless seemed long, and I fear, tedious; yet even so, it cannot be regarded as more than the merest sketch, and I shall be fortunate if it is even considered accurate by those entitled to an opinion on the subject. Nevertheless, we are now in a position to judge how far it is appropriate to use the two sets of tables, i.e., those of the normal curve, typified by Sheppard's, and Student's, in the interpretation of agronomic work.

APPLICATION TO AGRONOMY

It may be assumed that the object of all agronomic experiments is to find out whether some change of practice is likely to benefit farmers who follow it. The change is commonly of manure or of seed, but sometimes of method of operation. In order to simplify matters, it is proposed in the first place to deal with a change typified by the replacement of one variety of cereal seed by another.

Taking this simple case, the following points must be borne in mind when using the tables in order to judge of the significance of conclusions:

1. The population to which the conclusions are to be applied is one of yields of cereals grown in fields on the large scale. That being so, the population of which the experiments are to be a sample must not differ in any essential point from this, and in particular must be coextensive with the possible large-scale population.

Thus, if it is desired to estimate the result of replacing variety A by variety B over an area part of which is affected by drought and part not, the experiments must be spread over land subject to both sets of conditions, and even then it is best to regard them as belonging to two separate populations.

Similarly, in a variable climate (and where does the climate not vary?), the experiments must be carried over a series of years to correspond to that population of large-scale practice which is spread over the future.

[3] See footnote 11 on p. 718.

Again, there is a disproportionate amount of border in any reasonable size of experimental plat. This border must either be in contact with another variety or with ground unoccupied by crop. In either case the yield of the border strip is liable to be different from that of the interior, so that if the results are to be applied to the large-scale population of which the border forms a negligible fraction, it must be rejected.

Lastly, as far as may be, large-scale methods of agriculture should be used. Granted that it is often not possible, there is a danger that results may not be applicable to the farmer's case every time this principle is departed from, and every result obtained by small-scale methods should be rigorously checked on the large-scale before making recommendations to the farmer.

2. Generally speaking, but not necessarily, the population of large-scale yields with which we are concerned, is a population of "differences," i.e., some such question as the following is asked, "By how much may we expect the yield of variety B to exceed that of variety A if they were sown alternatively on the same soil in the same season?"

That being so, it is clear that the observed differences will not represent the true differences even in the sample plats as two crops cannot occupy the same place at the same time. Observed differences will miss the mark not only because the experimental soil and the weather experienced by the experiment may not be random samples of the soil and weather to be explored, but also because the actual plats laid out for the two varieties will usually differ in fertility. This is one of the largest sources of errors in field experiments.

Nevertheless, we are still dealing with a sample of differences and it is clearly advantageous in this simple case to do all calculations in terms of differences.[4]

This is not to say that percentages should never be used; that is another method of substituting one figure for two which has its

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[4] Note that the formula connecting the S. D. of a difference with those of its components is $\sigma^2_{A-B} = \sigma^2_A + \sigma^2_B - 2r_{AB}\sigma_A\sigma_B$, where σ_{A-B} is the S. D. of A—B and so on, and r_{AB} is the correlation between A and B. Only if $r_{AB} = o$ does this degenerate into what I may call the astronomer's formula:

$$\sigma^2_{A-B} = \sigma^2_A + \sigma^2_B.$$

In any well planned experiment r_{AB} is high, and there is considerable advantage in calculating the odds according to the correct formula. By considering the *differences* at once, we avoid all this difficulty of correcting for correlation.

In some American work the taking of differences seems to be considered the essential point of what they are kind enough to call "Student's Method,"but this old artifice must at least date back to Noah, who doubtless, had occasion to estimate the comparative appetites of his male and female passengers.

uses, but percentages should be used with the greatest care, they are fertile mothers of fallacy.

3. In using either of the tables we assume that the experimental results are a sample drawn from a population distributed normally. This is doubtless very often nearly true, but the limited number of experiments usually prevents us from being sure of it. What, then, is the extent of the uncertainty arising from this cause? The answer is, that if *we have enough data* no appreciable error is introduced. since even if the population is not normal the distribution of the means of large samples is very nearly so, but with very few repetitions we have to fall back on the general experience that such frequencies as those of yields are generally not badly represented by the normal curve, and hope for the best. Fortunately, the approach to normality of the distribution of the means of samples is very rapid, and appreciable errors are not likely to arise from *this* assumption, if we are dealing with the mean of more than a dozen repetitions.

4. Even supposing that an assumption of normality is justifiable, Student's tables must be used in calculating from *small* samples the probability that the results could have occurred by chance. To use the other method is definitely wrong, especially as it gives too high an estimate of the reliability of the results.

5. That being so, the only object in calculating the probable error in such cases is to compare with other experiments. Even for this purpose it is necessary with small samples to divide by n-1 and not by n to reach the mean square. But indeed "probable errors" derived from only two or three cases are so subject to chance that it is somewhat doubtful whether any useful purpose is served by calculating them. For example, if 10 were the value of the "probable error" of a population and values were to be found from samples of two or three, only 49% of the values would lie between 5 and 15 in the case of samples of two and but 68% in the case of samples of three.

The use of n-1 as divisor is also necessary in calculating a standard deviation from a large number of small samples of size n, which H. K. Hayes[5] proposes to call the "Deviation from the Mean Method."

It is necessary to remember that the correct formula to use is

$$\sigma = \sqrt{\frac{S(d^2) \times n}{N(n-1)}},$$

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[5] Control of soil heterogeneity and use of the probable error concept in plant breeding studies. Minn. Agr. Exp. Sta. Tech. Bul. 30. 1925.

when d is the deviation from the mean of the sample and N is the total number of deviations. When n is quite small this correction makes an appreciable difference.

6. Frequency curves are reached by assuming an infinitely large population and an infinitely small unit of measurement, and there is no trouble in *imagining* an infinitely large population though we have only to deal with the finite sample before us. But the unit of measurement must be the same for both, and, therefore, not only not infinitely small but as large as is convenient or customary. This is another of the discrepancies between the facts and the mathematics which does not matter very much *as long as the samples are large*, but may make a good deal of difference when they are small. With small samples the unit of measurement should be quite small compared with the difference which is being measured. For example, Student's table has been made to give absurd results by supposing that all the values happened by chance to coincide, when the odds became infinite. The probability that results should have the same value is not negligible when the unit of measurement is large but becomes vanishingly small as the unit of measurement is decreased, until, in the limit, the infinite odds only occur infinitely seldom. Nevertheless, when the repetitions are few and very high odds are obtained by the use of Student's tables, it is well to consider whether the result is not due to a value of the Standard Deviation having occurred which is much smaller than usual, and if this seems likely, to discount the apparent certainty accordingly. The tables are calculated to give the odds correctly if *all* the available information is contained in the sample. If additional information is available such as that the Standard Deviation of similar experiments is usually larger, we are quite entitled to draw attention to it, even though it may not be possible to introduce it into the calculations. In fact, tables can only be an aid to, and not a substitute for, common sense.

7. The experiments must be capable of being considered to be a *random* sample of the population to which the conclusions are to be applied. Neglect of this rule has led to the estimate of the value of statistics which is expressed in the crescendo "lies, damned lies, statistics."

Well-conducted experiments can often be supposed to give results which are random samples of the population of possible differences between the yields of plats sown with varieties A and B which could be grown on the experimental area under climatic conditions similar to those of the season in which the experiments were carried out, but it must be confessed that in some cases it is only by courtesy that experiments can be considered to be a random sample of *any* population. In such cases the greatest care must be exercised in drawing conclusions.

Nevertheless, we need not go as far as S. C. Salmon[6] who says, "It is with this source of error (soil heterogeneity) that Student's method may entirely fail," and proceeds to illustrate this by a comparison of yields in a tillage experiment carried out on two plats over a period of 10 years. With all respect, I do not think Salmon credits the user of the method with common sense. For he supposes that as the result of this comparison it will be concluded that the fact that one of the plats gave significantly higher yields than the other will be put down to the tillage treatment.

A moment's consideration shows, however, that the population from which the sample was drawn is a sample of differences of yield between *these two plats* in all possible seasons; whereas, considered as a sample of difference in yield due to tillage treatment in all soils similar to that experimented in, it is only *one* case from which, of course, *no definite conclusion can be drawn* either by Student's method or any other. If, however, ten repetitions had been made *with an arrangement of the plats which could be considered random*, the population sampled would have been that of "all similar soils," and the error introduced by soil heterogeneity would have been weighed and allowed for by the use of the tables.[7]

8. To sum up, *the experiments must be conducted in such a way that their results may be capable of being considered to be a random sample of the population to which the conclusions are to apply.* The unit of measurement must be small compared with the differences likely to be found, and the replications must be sufficient: (a) To give significance to the mean difference, and (b) to give a sufficiently close estimate of the variability to enable us to measure that significance with accuracy.

And here it may be pointed out that in some cases, could we but know the variability accurately, very few experiments would be required to demonstrate significance. If, to take an extreme example, a difference of ten units is found between a single pair of experiments and it is known from other work that in this case the Standard Deviation of a single difference is likely to be in the neighborhood of two units, a considerable, though somewhat indefinite, degree of confidence could be reposed in the result. This leads me to suggest that a careful tabulation and examination of Standard Deviations of experiments conducted at each station might be very valuable as showing within what limits the Standard Deviation of a new experiment might be expected to lie, and what sort of weight might be given to a result which would otherwise lack significance owing to want of knowledge of the variability. Useful though this might be, it is clearly better to arrange the experiments so that we shall have sufficient replications to lead to significance without going beyond the experiment itself.

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[6] This JOURNAL, 16:717–721. 1924.

[7] As Hayes (*loc. cit.*) has also complained that when comparing different seasons' yields Student's method does not allow for soil heterogeneity, I should like to emphasize that it may be used to estimate the uncertainty due to the season or to the soil heterogeneity, or even to both, provided we are satisfied that the experiments may be considered to belong to a single population. To compare mere average yields in different seasons and then to complain that no account has been taken of soil heterogeneity is as if a man were to feed wheat into a mill and then complain that the resulting meal "had entirely failed to make oaten porridge."

Elsewhere[8] I have drawn attention to Beaven's half drill strip method of comparing two varieties of cereals—a method which seems to me to fulfill the necessary requirements when but two varieties are in question. Here I propose to deal shortly with R. A. Fisher's "Latin Square" arrangement of experimental plats. This arrangement is calculated to reduce and allow for the error introduced by soil heterogeneity and is suitable for work on any scale from rod rows or small rectangular plats up to large scale plats of all sizes, provided always that the borders of small plats are discarded or that there is room enough for large plats.

Fisher outlines the method of the Latin Square on pages 229 to 232 of his book on *Statistical Methods for Research Workers* (Messrs. Oliver and Boyd, Edinburgh), and bases it on the following principles:

1. If there are contributory sources of variation *which are all independent*, the variance of the whole will be the simple sum of the variance contributed by all the sources. As mentioned above, Fisher defines variance as the Square of the Standard Deviation, or in the case of errors, as the mean square of error. We may therefore, for example, be able to analyze a total variance into: (a) That part contributed by the varieties (of seed or culture) having different yields; (b) that part contributed by say a East to West heterogeneity of soil; (c) that part contributed by say a North to South heterogeneity of soil; and (d) a random effect of soil heterogeneity not included in (b) and (c), which are not random.

[8] Biometrika, XV:271 et seq. 1923.

2. It is possible to arrange n plats of each of n different varieties in a square[9] so that each row and each column of the square contains one plat of each variety, but that otherwise the arrangement is "random." Having done so, we can estimate variances (a), (b), and (c), whence by subtracting their sum from the total variance of the n^2 plats, we can estimate variance (d) which is now the only one which affects the comparison between the varieties.

Fisher's justification of his method might perhaps be considered to come under the head of mathematics, which we have agreed to avoid, so assuming its correctness we may proceed to illuminate the subject by the consideration of a simple example.

Let us suppose that we are to test four varieties (A, B, C, and D) of a cereal by sowing four plats of each in a Latin Square. We have to arrange the 16 plats so that each row and column of the square contains one of each of the varieties, and yet the arrangement is otherwise to be random. We first proceed to draw a diagram with four rows and four columns to represent the 16 experimental plats. By suitably allocating four faces of a die, we can throw to find out which variety shall occupy the left top corner. Let us suppose B. We then proceed along the top row, throwing a die each time, and get C and A. The fourth must be D. Next, the left hand column is suitably filled in by D, C, A. Note when there are only three possibilities two faces can be allocated to each variety and when only two, three faces.

The intersection of the second row and column can now only be filled by A or B, and a throw of the die makes it A. The intersection of the second row and third column may be B or C, and we find C, the last of the second row is therefore B, and the last column must
D
be B or there would be two C's in the third row.
A
C

Finally, the intersection of the third row and second column may be B or D, and a throw of the die makes it B, which fixes the remaining three places.

B	C	A	D
D	A	C	B
C	B	D	A
A	D	B	C

This, which was actually arrived at by die throwing, is one of the

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[9] The actual shape of the Latin Square will be similar to that of one of its constituent plats and may therefore be only diagrammatically square. This is quite immaterial to the argument.

288 possible arrangements, and we may further use it for purposes of illustration by supposing that the yields were those of the S. E. corner of Montgomery's[10] diagram of plats of Turkey wheat given on page 37 of his classical "Experiments in Wheat Breeding."

The yields in grams are as follows:

					Sums of rows	Means of rows
	B 617	C 683	A 726	D 835	2,861	715.25
	D 602	A 662	C 640	B 700	2,604	651
	C 665	B 736	D 630	A 598	2,629	657.25
	A 609	D 706	B 790	C 678	2,783	695.75
Sums of cols.	2,493	2,787	2,786	2,811	10,877	
	623.25	696.75	696.5	702.75		General mean 679.81

										Average
A =	726	+	662	+	598	+	609	=	2,595	648.75
B =	617	+	700	+	736	+	790	=	2,843	710.75
C =	683	+	640	+	665	+	678	=	2,666	666.50
D =	835	+	602	+	630	+	706	=	2,773	693.25

Variance of Columns

Taking 2,600 as a working mean, the deviations of *sums* of columns from this are:

	—107	and the squares	11,449
	+187		34,969
	+186		34,596
	+211		44,521
Total	477		125,535
Deduct	$\frac{1}{4}(477)^2$	=	56,882.25

68,652.75 ÷ 4[a] = 17,163.1875

[a] Divide by 4 because we have worked with *totals* and we want to change to means.

Variance of rows

As above, deviations of sums of rows from 2,600 are:

	+261	and squares	68,121
	+ 4		16
	+ 29		841
	+183		33,489
Total	+477		102,467
Deduct	$\frac{1}{4}(477)^2$		56,882.25

45,584.75 ÷ 4 = 11,396.1875

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[10] U. S. D. A. Bur. Plant Ind. Bul. 269.

Variance of varieties

Deviations of sums of varieties from 2,600 are:

	— 5	and squares	25
	+243		59,049
	+ 66		4,356
	+173		29,929
Total	477		93,359
Deduct	$\frac{1}{4}(477)^2$		56,882.25
			36,476.75 ÷ 4 = 9,119.1875

Total Variance

Taking 680 as a working mean the deviations of the yields of the individual plats are as follows:

Yield of plat —680	Squared
— 63	3,969
+ 3	9
+ 46	2,116
+155	24,025
— 76	6,084
— 18	324
— 40	1,600
+ 20	400
— 15	225
+ 56	3,136
— 50	2,500
— 82	6,724
— 71	5,041
+ 26	676
+110	12,100
— 2	4
— 3	68,933
Deduct 1/16 $(3)^2$	.5625
	68,932.4375

We have next to perform an operation analogous to that of multiplying by $\sqrt{\frac{n}{n-1}}$ in the case of finding the Standard Deviation from a sample of n. Fisher's way of doing this is given below in the table of the analysis of the variance:

Variance due to	Degrees of freedom	Sum of squares	Variance	Standard deviation
Varieties	3	9,119.19		
Columns	3	17,163.19		
Rows	3	11,396.19		
Remainder	6	31,253.87	5,208.94	72.2
Total	15	68,932.44		

In the above table the first column is descriptive of the variance arising from different sources.

We are chiefly concerned with that entitled "Remainder," which enables us to arrive at an estimate of the random errors which are not associated either with variety or with that part of soil heterogeneity common to whole rows or columns. The second column gives the "Degrees of Freedom." In the first, second, third, and fifth rows of the table the degrees of freedom merely represent one less than the number in the sample (4 varieties, 4 columns, and 16 plats altogether) and are strictly analogous to the n–1 quoted above. The number in the fourth row is obtained by making the first four rows add up to the total of the fifth.

The principle of degrees of freedom is widely applied by Fisher and the idea behind it is that if there are a number n of variates of which the mean is used in the calculation, all but one of them can take any possible value; but when n–1 values have been chosen the last one is fixed by the mean, so that only n–1 variates are free to vary. If, in addition, some other statistic is used, such as the Standard Deviation, only n–2 of them can be varied, and so on.

In this case there are 15 degrees of freedom in the total and three sets of three degrees of freedom are taken up by the varieties, the rows, and the columns, leaving six for the determination of the variance of the random error.

In the third column the first, second, third, and fifth rows are given by multiplying by 16 (a), (b), (c), and (d) calculated above, and the fourth by making the first four rows add up to the last.

In the fourth column the required variance is given by dividing the figure in the third column by that in the second and from this is obtained the Standard Deviation by extracting the square root. If this had been found from enough degrees of freedom, we could find the Standard Deviation of the difference between two varieties appropriate to use with tables of the Normal Curve by dividing by $\sqrt{\frac{4}{2}}$ (the 2 in the denominator being due to the fact that we are to judge of the significance of a *difference*, and the 4 to the number of replications), which would give a Standard Deviation of about 50, while the greatest difference between "varieties" is only about 60. Obviously, this would not be significant, as indeed in this example it should not be, the "varieties" being all the same—Turkey Red wheat. In fact the significance is even less, as with only six degrees of freedom Student's table must be used.[11]

Unfortunately, Student's tables were constructed some time before the Latin Square was thought of, and it requires some care to enter the table aright.

In the first place we have to enter the table under the heading $n = 7$, one more than the degree of freedom, since if Student's table had been headed with the degrees of freedom, the headings would have been one less.

Secondly, to obtain "z," we divide the difference (say B—A which is 62) by the S. D. $\times \frac{\sqrt{2} \times \sqrt{7}}{\sqrt{4}}$ in which the $\sqrt{2}$ corresponds to the fact that we are considering a *difference*, the $\frac{\sqrt{7}}{\sqrt{4}}$ to the fact that the original table was constructed so as to give the probability for means of 7, while we only have means of 4. z is here, therefore, $\frac{62}{130}$ or just under 0.5, which if looked out in this table under $n = 7$ gives $P = 0.86$, a satisfactorily non-significant result.

Looked at from another point of view we should require a difference between varieties of not less than 100 grams or some 15% for it to be worth while testing under such conditions as Montgomery's with only four plats of each variety.

I have illustrated the method on a Latin Square of four plats per side choosing a small number so as to make it easy to follow the arithmetic, but in point of fact *four replications are decidedly too few* and much larger squares are recommended. One of the disadvantages of this particular illustration has been that whereas usually the variance is much reduced by the subtraction of that associated with rows and columns, there has by chance been very little reduction in this case.

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[11] This applies to the tables given in Biometrika, VI:19; and XI:416; and those in the new edition of Tables for Statisticians and Biometricians. The tables in Fisher's *Statistical Methods for Research Workers* and those which are to appear in the next number of *Métron* are given under the headings of the degrees of freedom.

The following table gives other possibilities—

Number of varieties	Number of replications	Total number of plats	Number of degrees of freedom for calculation of error	Heading of column to be used in Student's tables	Factor to multiply S.D. by in calculating Z
4	4	16	6	7	$\sqrt{\frac{2\times 7}{4^{a}}}$
5	5	25	12	13	$\sqrt{\frac{2\times 13}{5^{a}}}$
6	6	36	20	21	$\sqrt{\frac{2\times 21}{6}}$
7	7	49	30	—	Use Normal Curve with S.D.$\times\sqrt{\frac{2}{16-3^{b}}}$
4	16	64	46	—	

[a] Number of replications. [b] Three less than the number of replications.

In the last case there will be two replications in each row and column, and care must be taken that the arrangement is really random, e.g., if one plat of A has been fixed in a row the chance of filling the next with A must be only ½ that of filling with one of the other letters not yet represented in the row.

CONCLUSION

To sum up, in planning agronomic experiments *use plenty of replications* and make quite sure that your results are capable of being considered to be a random sample of the population about which you wish to draw conclusions.

BOOK REVIEW

THE PRODUCTION OF COTTON

By Gilbeart H. Collings, Assistant Professor of Agronomy, Clemson Agricultural College. The Wiley Agricultural Series, edited by J. G. Lipman. John Wiley & Sons, Inc., New York. 1926. $3.50 net.

This, the tenth number of the Wiley series of agricultural text books, was prepared by the author for use as a college text. It is an outgrowth of lecture notes used in teaching a course in cotton at Clemson College for eight years It is based upon what the author believes to be the practices of the best growers of cotton, supplemented by the results of American and foreign research.

"The entrance of the cotton boll weevil into the Cotton Belt brought about marked changes in the common fertilizer and cultural practices followed in the growing of cotton. * * * * the author has found it rather difficult in some cases to select out of the mass of conflicting data the most trustworthy information relating to the fertilizers and cultural practices under boll weevil conditions. In such cases he has often cited practices followed under non-boll weevil conditions and then given such additional experimental evidence as appeared to indicate the best practices to follow under boll weevil conditions." (From author's Preface).

The book contains 214 pages of text matter, divided into 22 chapters under the following headings: Early History of Cotton; Climatology of Cotton and its Relationship to Cotton Production; Principal Soil Regions of the Cotton Belt; Morphology of the Cotton Plant; Botanical Classification of Cotton; Physiology and Chemistry of the Cotton Plant; Classification of American Upland Cotton Varieties; Culture of Cotton; Fertilizers for Cotton; Diseases of the Cotton Plant; Insects of the Cotton Plant; Harvesting of Cotton; Ginning and Baling of Cotton; Warehousing of Cotton; Marketing and Transportation of Cotton; Grading and Classification of American Upland Cotton Lint; Breeding of Cotton; By-products of the Cotton Plant; Feeding Value of Cotton; Cotton Regions of the World; History of Cotton Production in the United States; and Production of American-Egyptian Cotton.

An appendix of 32 pages presents 16 tables of data concerning the production and consumption of cotton and its by-products.

The book will undoubtedly prove useful as a text in those colleges which have special courses in cotton culture. It will also be useful to the better educated growers of the crop.

The text shows a serious lack of careful editing. For example, many paragraphs are written in a mixture of the discoursive, the argumentative, and the hortatory style. In others, the first, second, and third personal form of presentation are intermingled. There are many cases of colloquial, or at least unusual, uses of common words. These evidences of careless diction, while they may not seriously interfere with the usefulness of the book as a text or reference, are regretable as indicating a low standard of English composition in agronomic literature of college grade.

In mechanical make-up, the book is excellent, being uniform with the other members of the series in quality of paper, arrangement of material and typography, and binding. The illustrations are generally well chosen and well reproduced. (R. W. T.)

NOTES

COMMENTS ON THE QUESTION "DO LEGUME LEAVES HASTEN THE CURING PROCESS BY PUMPING MOISTURE FROM THE STEMS?

I note that the question, "Do legume leaves hasten the curing process by pumping moisture from the stems?" has been discussed by C. J. Willard in the May, 1926, issue of this JOURNAL. Since the author questions a statement in my book on "Crop Production and Soil Management"[1] I would like to raise the following points:

1. In a discussion, from the physiological standpoint, of the continued loss of moisture through the leaves, attention should be given in addition to a continuance of transpiration through the stomata. A very considerable loss of moisture also takes place through the entire leaf surface and, of course, the leaf surface is much greater than the stem surface—another reason for maintaining the leaves.

2. When fresh leaves or stems are clipped, the stubs continue to exude moisture or "bleed." This is, of course, not representative of field conditions for no mowing or raking machinery treats the leaves in this fashion. If leaves and fine stems are allowed to dry rapidly, does not a practical sealing occur at the base of the leaf or in the stem under field conditions? Apparently Mr. Willard does not make allowance for losses from the fresh cuts.

3. Conditions existing in the ordinary laboratory are not representative of field conditions.

4. Five stems is an unusually small number on which to base conclusions.

5. A study of the data presented shows such confliction of results that a definite conclusion is impossible, except that the field offers room for much additional work.

6. From a practical standpoint there is no doubt that the curing of alfalfa, sweet clover, and practically all legume hays in windrows or cocks retains the leaves and gives a much better quality of hay of much higher feeding value.

7. There are now three makes of left-hand, side-delivery rakes which work against the heads of the stems in the swath, throwing the

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[1] John Wiley & Sons.

hay into a loose windrow with a majority of the leaves inside. Four years' experience with this method at the Michigan Experiment Station shows that the use of the rake immediately after cutting or within two or three hours, while the leaves are still in a green condition, gives best results. In good waether, well-cured alfalfa hay is secured in from 18 to 24 hours with one turning of the windrow.

8. I would seriously question Mr. Willard's statement that, "It would seem that as a usual practice it would be best to allow hay to cure in the swath as long as possible without allowing the leaves to become brittle, using the tedder where desirable to loosen the swath and equalize the exposure, and then put the hay in the windrow or cock to complete curing. This is the common practice of the best farmers in putting up legume hay." The most improved and effective way of curing alfalfa and other legume hay is in the windrow or cock before a long period of curing in the swath has taken place. To use a tedder on alfalfa or any other legume hay is, in my estimation, an exceedingly undesirable practice. No more effective machine for knocking off leaves has been developed, and the objective in getting best results in curing hay is to retain the leaves.—J. F. Cox, *Professor of Farm Crops, Michigan State College, East Lansing, Mich.*

CONCERNING THE CURING OF LEGUME HAY

I have noted with interest the paper in this JOURNAL for May, 1926, covering the results of certain laboratory experiments conducted by Professor C. J. Willard of Ohio State University, with the intention of throwing more light on the curing of legume hay.

In this article Professor Willard takes issue with a pretty generally accepted principle, that leaves, under the right conditions, assist the stems of forage plants in exuding moisture during the hay curing process. It seems very doubtful whether such a widely accepted theory, particularly in its practical application, can be upset by laboratory experiments with a few stems of alfalfa, in no way approximating conditions of hay in the field. As Professor Willard states, many of the figures are inconsistent and "probably due to various experimental errors." In general, they support the belief that transpiration does continue after the hay is cut.

The danger of the assertions made in his article lies not so much in the upsetting of beliefs in certain plant physiological actions as in the applications that are made of plant physiology to practical hay making in the field.

Two things are of importance in the making of quality hay economically, *viz.*, the saving of time and labor, and the retention of the leaves, color, and aroma of the forage. The saving of the color and aroma is influenced greatly by weather, but an expert hay maker can save the leaves, with their greater food value, despite unfavorable weather. With good weather, it is possible to cure a leafy, rich, green forage of pleasing aroma, that will top the market and secure maximum benefits when it is fed.

Such hay is best made, not by permitting it to "lie in the swath as long as possible without allowing leaves to become brittle," using a tedder and merely finishing it in the cock or windrow, as is suggested by Professor Willard. It is obtained by getting the forage into a loose, fluffy windrow as soon as possible. The left-hand, side-delivery rake, manufactured by at least three implement companies, can follow the mower almost immediately delivering a windrow in which 60 to 80% of the leaves are under cover, with the thicker and more juicy stems exposed.

This mechanical condition of the windrow is to be desired, regardless of the physiological action which takes place during the drying of the hay.

If, as Professor Willard asserts, the leaves give no assistance to the stems in exuding moisture, it is desirable that the stems be gotten up from the bottom of the swath where they are prevented from drying out by an almost complete covering of leaves. On the other hand, if, as most of those experienced in making quality hay believe, the leaves with their expansive surface continue to assist the stems in ridding themselves of moisture so long as the moisture passages are not dried up, it is desirable that the leaves be kept from the direct sunlight, so they may continue to function as long as possible. In either instance, the same field practice would be indicated as desirable. Further, this protection of the leaves is assurance against loss of color, sure to result from allowing hay to lie in the swath, a method long since abandoned by good alfalfa growers. Each hour hay is thus neglected adds to the destruction of desirable color and the loss of leaves.

The curing of hay in the swath for any considerable length of time is the surest way to dry the leaves prematurely into a brittle state, before the stems are cured, with the result that they are lost during harvest or when the hay is fed out. This loss of leaves is most effectively augmented by the use of the tedder recommended by Professor Willard.

The superintendent of the Michigan State College farm has been putting up over 100 acres of alfalfa hay each year for the past three years by raking the hay immediately after it is cut. In comparing the appearance and condition of this hay with hay allowed to wilt in the swath and cure in the cock, he states that he not only saved time and labor by using this system, but that this hay had a better color and retained more of its leaves. This was particularly noticeable as the hay was being fed out. Where hay wilted in the swath and later finished in the cock was thrown to the barn floor at feeding time, a large pile of alfalfa leaves accumulated; but where the other alfalfa was thrown out, it fed away very cleanly.

During 1924, hay raked immediately after cutting passed through eight rains. Each time, the windrow was merely turned with the side-delivery rake to get it loosened and off the damp ground. The next spring, this hay, coming out of the mow, was graded U. S. No. 2, by the chief federal inspector. Its color had been injured by the rains, but it retained its leaves. Hay cured in the swath and cock which went through the same weather was practically worthless.

The rapid adoption by best alfalfa growers of methods of hay making which involve the immediate raking of the hay and curing it in the shade of a windrow, and the excellent results which these farmers are securing when their hay is fed out, is striking evidence of the value of this practice. It is a practice sure to be much more widely adopted unless practical research under conditions closely approximating those in the hay field bring to light something better.—H. C. RATHER, *Extension Specialist in Farm Crops, Michigan State College, East Lansing, Mich.*

REPLY TO PRECEDING NOTE

Professor Rather's criticism is concerned largely with the practical details of hay making, while the writer's entire purpose in carrying out the experiments reported was to test the correctness of two theories of hay making, expressed by Professor Rather in the article previously cited by the writer as follows: "The moisture contained within the plant is normally lost by evaporation through the leaves. . . Strong sunlight will quickly wither these leaves and shut off the moisture passages through which the stem moisture should move." The correctness of these theories can only be tested by laboratory experiments.

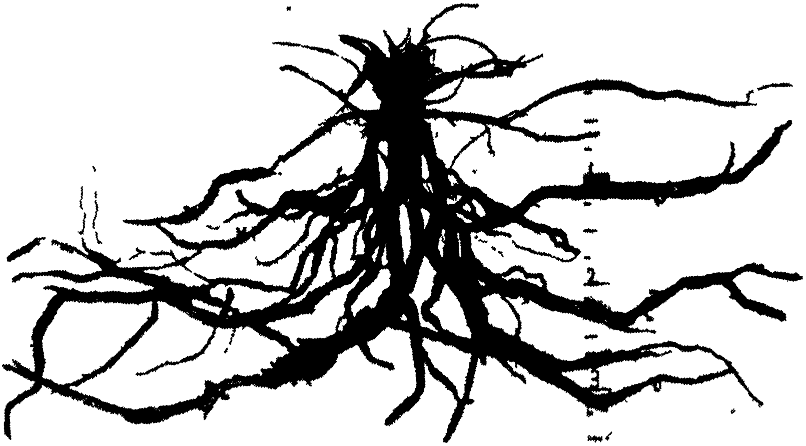
It is entirely true, as Professor Rather points out, that it makes little practical difference whether these theories are correct or not. Regardless of explanations, the only real tests of a method of hay making are the quality of hay produced and the economy of the method. Such tests can only be made in the field; but if we make physiological explanations of our field results, they should be correct ones.

In actually putting up alfalfa in the field, the writer doubts if he and Professor Rather would differ very materially. No reasonably observant man would use a tedder on alfalfa after it was dry enough to lose any leaves in the tedding. Ordinarily a tedder is an unnecessary implement, but three years ago, in putting up 90 acres of alfalfa on the University farm, the writer found a tedder very valuable immediately after cutting heavy lodged alfalfa which had been bunched and rolled together by the divider board of the mower, in loosening this tangled heavy material and equalizing its exposure to the air.

"Curing in the swath as long as possible without allowing the leaves to become brittle" is *not* to "leave it in the swath for any considerable length of time." In good drying weather it may be only an hour. Since the article by the writer clearly recognizes the better quality of hay to be secured by curing the hay in the windrow, the only difference between his recommendation and that of Professor Rather is that Professor Rather recommends raking it once after cutting, while the writer suggests taking advantage of the more rapid drying in the swath to hasten the initial curing of the hay. Since speed of curing is very important in getting hay out of the way of storms, the writer still feels that this suggestion is justified. However, he is open to conviction, and is now engaged in field experiments which he hopes will furnish further information on the complex questions involved.—C. J. WILLARD, *Assistant Professor of Farm Crops, Ohio State University, Columbus, Ohio.*

AN INTERESTING ROOT SYSTEM

In the spring of 1919 the writer secured 25 Kudzu roots from the U. S. Department of Agriculture. These were planted along the fence around the crops garden. Except for a space around each Kudzu plant, the fence row was left in bluegrass, and the plants were allowed to take care of themselves. They made a very vigorous growth, in later years burying the fence each summer in a mass of vines which also extended for 20 feet or more on each side of the fence. In April 1925 it was necessary to abandon that location for the crops garden, and in attempting to move these Kudzu plants such remarkable root systems were discovered that a considerable portion of one of them was dug out. This root system is illustrated in the accompanying figure, which shows clearly the size and extent of the roots of this herbaceous leguminous vine. Later, the vertical roots were followed to a depth of 6½ feet, where they ended rather abruptly. The roots were not dug out farther horizontally, though they certainly extended much farther. With such a reserve of stored food as this to draw on, it is little wonder that Kudzu grows with amazing rapidity during June and July.



The essential facts concerning Kudzu in Ohio have already been published by Williams[1]; but some details may be added here, lest it be thought that the crop is being recommended for general use. In 1923, encouraged by the growth of the vines in the crops garden, an acre was planted to Kudzu roots, spacing them 3½ by 7 feet. Less than half of these roots grew; but the ones which lived made a good growth. The next spring, following a winter which killed much red clover and common alfalfa, every plant was dead.

In the spring of 1925 we planted 200 more roots, spacing them 3½ by 3½ feet. Only about a fourth of these grew, but again the plants which lived made a vigorous and satisfactory growth. This spring less than a dozen plants are still alive, although the winter was so mild that crimson clover lived over perfectly and volunteer Fulghum oats in winter wheat also lived over.

In every instance the Kudzu crowns have been killed. In many plants which have been dug for observation the upper 3 to 6 inches had rotted, while the lower roots were still sound. Apparently buds do not ordinarily start on these deeper roots, so that like alfalfa, when the crown is killed, the plant is killed also.

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[1] WILLIAMS, C. G. Kudzu, a failure in Ohio. Ohio Agr. Exp. Sta. Bul. 382: 24–25. 1924.

Kudzu makes a splendid ornamental vine. There is one such vine beside a house in Columbus which has been there for at least 15 years, withstanding the long severe winters of 1916–17 and 1917–18. Perhaps the reason these plants and those along the fence in the crops garden have lived when the field plants have died is that the former had a certain amount of surface protection. Again, it may be that established plants are hardier than those recently planted. At all events, it is not wise to recommend to Ohio farmers a crop which is extremely expensive to start, questionable in value, and which so far has resulted in nothing but failure when grown under field conditions.—C. J. WILLARD, *Assistant Professor of Farm Crops, Ohio State University, Columbus, Ohio.*

AGRONOMIC AFFAIRS

NEWS ITEMS

The professorial titles of Drs. W. E. Castle and E. M. East at Bussey Institution at Harvard University have been changed to Professors of genetics from professor of zoology and of experimental plant morphology, respectively.

Frederick B. Smith has been appointed Associate Professor of Agronomy at the Colorado Agricultural College and Experiment Station, effective August 1, 1926. James D. Marshall, who has been connected with the Department of Agronomy for the past ten years, has resigned.

E. V. Abbott, formerly Assistant Plant Pathologist of the Louisiana Agricultural Experiment Station, has been appointed Assistant Chief in Soil Chemistry and Bacteriology of the Iowa Agricultural Experiment Station and Assistant Professor of Soils of Iowa State College, succeeding H. J. Harper, who resigned during the past year to accept a position as Professor of Soils at the Oklahoma A. & M. College.

J. Allen Clark, Agronomist in charge of Western Wheat Investigations for the Bureau of Plant Industry of the U. S. Department of Agriculture, addressed the seminar of the Agronomy Department of the North Dakota Agricultural College on July 29, discussing the work with wheat at 18 western stations.

L. G. McGrew, a 1926 graduate in agronomy at Clemson College, has been appointed to a fellowship in agronomy at the University of Kentucky for the coming year.

Dean A. R. Mann returns to duty at the State College of Agriculture at Cornell University on September 1, after two years spent as European Director for Agriculture for the International Education Board. Dean H. L. Russel, of Wisconsin, also returns to duty after a year spent as Asiatic Director for Agriculture for the same Board.

Prof. A. T. Kirssanoff, Chief of the Division of Agronomy of the State Institute of Experimental Agronomy of Leningrad, U. S. S. R., recently devoted ten days to a study of the agronomic and economic work being done at the North Dakota Agricultural College. While there, he addressed a seminar group upon the results of his 12 years' work at the Peat Experiment Station at Minsk, Russia.

Agronomists, agricultural economists, farm managers, and a group of interested foreign scientists and farm managers made up the personnel of the recent farm tour of eastern North Dakota by the Northwest Farm Managers' Association under the leadership of Cap E. Miller, Sec-Treas. of the Association and chairman of the Department of Agricultural Economics at the North Dakota Agricultural College. About 100 people made the tour covering 335 miles in the three days of the trip.

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ROOT CUTTING AS AN AID IN HARVESTING GRAIN SORGHUMS WITH A "COMBINE"[1]

JOHN P. CONRAD[2]

INTRODUCTION

That the difficulty of harvesting the grain sorghums is one of the most important reasons why this excellent crop is not more largely grown seems evident from a knowledge of its superior advantages. The ability of the sorghums to produce large yields on a limited amount of moisture, their deep-rooting habit, their drought resistance, their heat tolerance, and ease of cultivation—all proclaim their advantages for warm arid regions. The ability to remain alive though practically dormant when moisture seems lacking, and to resume growth again when moisture is applied, demonstrates the vitality of this plant. This very vitality, the ability to keep the moisture of life within itself under trying conditions, while a great advantage during the growth of the crop, is a disadvantage when it comes to its harvest. Even though the crop has been produced and the grain has filled, the plants still take advantage of any favorable conditions which are presented to keep on growing. Consequently, at harvest the farmer has on his hands a crop which contains too great an amount of moisture to gather safely in the condition it is in. During the advancing fall months, at best, conditions are but poor for drying out the excess moisture to secure safety in storing the final product.

In the fall of 1923, by comparing foot by foot the moisture in the soil under a crop of grain sorghums grown without irrigation with the theoretical wilting coefficient (Briggs and Shantz) of the soil, it

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[1] Contribution from the Division of Agronomy, University of California, Berkeley, Calif. Received for publication April 19, 1926.

[2] Research Assistant.

became evident that the major moisture requirements of the plants were being met by withdrawals below the 3-foot level. The idea grew that if the roots connecting the plant above ground to the source of moisture below could be severed the plant must dry up. A few days later, a limited proof of this idea was seen. A plant fully matured was standing upright in the field in a bone-dry condition. Examination beneath the surface of the ground showed that a gopher had gnawed away the roots in building its burrow, thereby killing the plant.

By following up these observations a harvesting system was worked out upon theoretical grounds in which the roots of the grain sorghum plants would be cut off by a blade to be run along 6 to 8 inches beneath the crowns of the plants. With the roots severed, the plants would dry out in an upright position within a few days. The grain could be harvested then by pulling a combined harvester or "combine" through the field. In case of rain after cutting, the plants would be wet somewhat, no doubt, but evidently most of the water would quickly run off. With a change to drying weather, after the storm, the heads would be standing upright, each by itself, giving wind and sunshine the maximum opportunity to bring them again to a condition dry enough to thresh.

EXPERIMENTAL

In order to test out this system on as many points as possible, appropriate plantings were made in the spring of 1925. As in all probability the apparatus for cutting the roots would be tractor drawn, it became evident that with varieties of grain sorghums taller than 3 feet the space between rows would need to be wider than normal. Plantings were made therefore with rows 84 inches apart, as well as with rows the normal 42 inches.

APPARATUS FOR CUTTING

A 6-foot, tractor-drawn orchard cultivator was equipped on the extreme of each side of regular cross-bars with an upright standard of ¾ inch by 2-½ inch steel. It was found necessary later to brace the standards, as shown in Fig. 1. A horizontal blade of soft steel (½ inch by 5 inches by 38 inches) with front edge sharpened was bolted onto the flange of each standard. Each blade with a pitch downward or "suck" of approximately 2 inches in the 5 of width was set at an angle of 45 degrees to the direction of the draft. This gave a cutting width of approximately 27 inches. Preliminary tests had shown that blades with no "suck," even though weighted down,

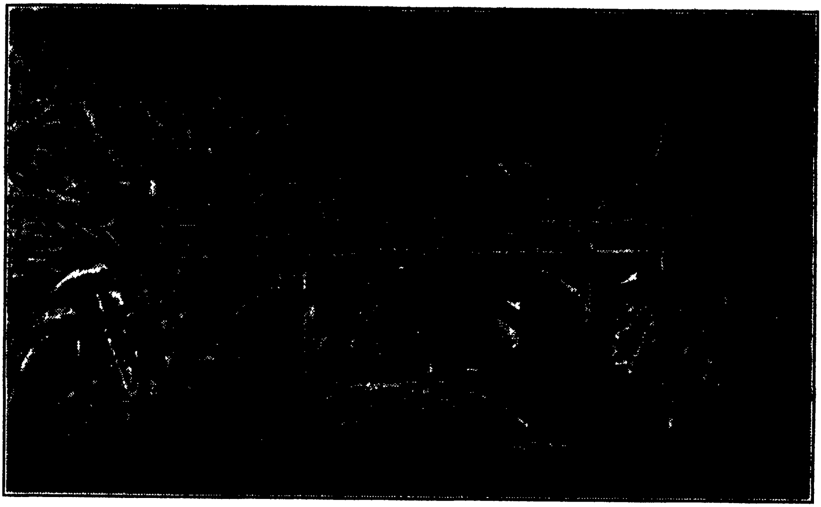

FIG. 1.—Apparatus used for root cutting ready to start on two rows of Double Dwarf Milo. After "tripping" as soon as the cultivator had gone 3 feet, the blades were cutting at a depth of 4 to 6 inches without tipping the plants over.

simply skimmed along 2 or 3 inches deep between the mulch and the firm ground beneath. Later tests showed that better results could be secured by bowing the blades down 2 or 3 inches in the center. This gave a deeper cut directly under the crowns where desired, and yet there was sufficient rise on the far side of the row to intercept most of the side roots there.

At times some difficulty was experienced in not having the cultivator "track" accurately behind the tractor. Ordinarily, a man riding the cultivator could shift his weight to offset this difficulty, but in practice it would be desirable to eliminate the necessity for a man. A cultivator designed to give an equal draft on each side should eliminate this difficulty. Blades accurately fashioned to be symmetrical, and running at equal depths on each side, should provide the approximate equality of draft desired. Better control of the cutting depth should be secured by wider spaced wheels, each with a wider tire and with provisions for placing extra weights on the cultivator frame. Later tests with heavy V-shaped cultivator blades secured from the manufacturer gave better control of the cultivator than the crudely fashioned ones first used as described. As these, however, had a cutting width of only 17 inches from the standard, it was necessary to cut on both sides of each row to kill the plants effectively. A traction-lift for the cultivator, in order to lift the blades out of the ground at the ends of the rows, was found to be almost indispensable for the most efficient work.

The tractor used was equipped with tracks. It was approximately 50 inches wide over all and was rated at 12 horse-power on the drawbar. With it, on irrigated soil (Yolo silt loam), it was possible to cut to an average depth of 6 inches at a speed of about 3 miles per hour. On land mapped as the same soil type, but not irrigated and consequently harder, the average depth was 4 inches at approximately the same speed.

EFFECT UPON SORGHUM PLANTS OF CUTTING ROOTS

As the roots are being cut, if the blade goes deep enough, the plant will quiver slightly, tip away from the cultivator, then tip toward it, and settle into place as if nothing had happened. If a plant has had its roots sufficiently cut, it may be easily lifted up an inch or more and, on being released, settle into place again. A plant not cut cannot be lifted in this manner, but must be practically pulled from the ground by breaking the many roots. Plants not cut deep enough will generally topple over as they tip away from the cultivator.

With all of the roots of each plant cut on a bright sunshiny day, there was unmistakable evidence of wilting within two hours. The following day the plants looked as if they had been hit with a heavy frost and were apparently dry enough to thresh in three to four days after cutting, though actual threshing was deferred somewhat longer. Plants recently irrigated, where all roots were cut 6 to 8 inches below the surface, went through practically the same rate of drying Where one plat was irrigated within half an hour after being cut on a cool, cloudy day, about 40% of the plants survived. In all other cases where roots were completely cut off at 9 inches or less below the surface of the ground, rapid drying of the plants resulted. Where all roots were not completely cut off on the irrigated plats, as where cutting was done on but one side of the row with a blade long enough to reach but 3 to 4 inches beyond the crowns, at a depth of 5 to 7 inches, there was no apparent effect on the plants. However, where cutting was done with these short blades on land not irrigated, the leaves died back considerably, but the stalks were apparently as full of sap as ever. Examination showed that side roots on the opposite side of the row from where the cutting was done were still in good condition and evidently supplying some moisture to the stalks and young leaves not injured.

EFFECT OF CUTTING ON DIFFERENT VARIETIES

Most of the tests were made with two strains of dwarf milo, namely, the Heileman strain, similar in characteristics to the Yellow Dwarf milo (C. I. 332), and the Double Dwarf milo, a strain with fairly erect heads and attaining a height between 20 and 36 inches. Two days after the former had been cut, whether grown with or without irrigation, this taller-growing variety had wilted flat upon the ground by the bending of the stalks just at or a little above the surface of the ground. The latter variety showed some tendency to wilt down following cutting, where grown with irrigation, but not more than 20% of the heads were upon the ground from this cause after ten days. No wilting to the ground after root cutting was observed with this variety where grown without irrigation, though the heads sagged somewhat. Whether this difference in wilting between irrigated and non-irrigated plants is due partly to the effect of irrigation upon the strength of the stalks, or entirely to the greater weight of heads of the irrigated milo, is not known.

Ten days after cutting, White Yolo had less than 3% of stalks wilted over, Dwarf Spur Feterita less than 15%, and White Durra less than 30%, where these varieties were grown without irrigation.

Due to this unexpected phenomenon of wilting to the ground, further tests were made with 18 varieties[3] which were being grown under irrigation for laboratory material. Four plants of each variety were dug up, each with a sod of soil adhering to the roots approximately a foot square and 8 inches deep. Each sod with the stalk of the plant as a handle was lifted to break the roots, and then was reset in the hole. All plants so treated dried out as had those cut with the tractor-drawn knives. The following varieites went for six weeks after this treatment through heavy north winds and a 2-inch rain without any tendency to wilt over: Fargo Straight-neck Milo (C. I. 809), Pink Kafir (C. I. 432), Red Kafir (C. I. 34), Blackhull Kafir (C. I. 71), Spur Feterita (C. I. 623), and Darso (C. I. 615).[4] The other 12 showed from 25 to 100% wilting over. These tests show the possibility of selecting varieties that will stand up for several weeks following root-cutting, or strains within varieties that will do so. Unfortunately, no lot of seed used in the larger plats, where cutting was done with the tractor-drawn knives, was the same as that used in the short rows where individual plants were dug up. Hence no conclusion can be drawn as to the equality of these two methods upon the wilting of the stalks to the ground.

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[3] Seed were secured from John B. Seiglinger, U. S. Dept. of Agriculture, Woodward Field Station, Woodward, Oklahoma.

[4] The stalks of this variety were inclined at an angle of 20 to 30 degrees from the perpendicular, as were the stalks of the rest of the row which had not been dug up.

RATE OF DRYING OF GRAIN AFTER CUTTING

One of the theoretical advantages of the root cutting of grain sorghums was that the heads would be up in the air, each by itself, and should consequently dry faster, not only after having been cut, but also after a rain. To test this out in comparison with hand heading and binding, samples of heads were taken at intervals from these lots as harvested. These tests were carried out with both White Yolo and the Double Dwarf milo. Only one sample from each of the six lots was taken at each time of sampling. The samples were dried in an electric oven at about 60°C. for a few days, and then all were exposed to the air of the laboratory for a month. The percentages of moisture computed on the basis of the air-dry weights are given in Table 1.

TABLE 1.—*Percentages of moisture (on the air-dry basis) of the grain of grain sorghums grown without irrigation and variously harvested.*

Variety	White Yolo			Double Dwarf Milo		
Method of harvest	Roots cut	Heads cut and piled	Stalks cut and bound	Roots cut	Heads cut and piled	Stalks cut and bound
Date of harvest	Sept. 27, 1925			Sept. 25, 1925		
Percentage of moisture on air-dry basis: before harvest	—	45.0	—	—	8.8	—
Sept. 27, 1925	—	—	—	4.8	8.3	10.0
Sept. 28, 1925	19.5	26.5	24.5	4.6	10.4	11.8
Sept. 30, 1925	17.0	13.1	16.0	2.7	2.7	4.9
Oct. 2, 1925	—	7.8	8.8	4.9	4.3	5.7
Oct. 5, 1925	8.9	7.2	8.8	4.7	4.0	6.2
Oct. 7, 1925	8.8	5.1	—	5.0	4.3	5.4

The expectations of large differences in rates of drying were not borne out under the conditions of these experiments. More data are necessary before definite conclusions may be drawn, but there is an indication that the grain of the plants whose roots had been cut dried out a little more rapidly at first than did the grain in the other methods of harvest. Because of the relatively dry fall, no opportunity was presented to test out the comparative rates of drying following a rain.

FIG. 2.—One foot of row of Double Dwarf milo plants half an hour after the roots had been cut with the blades shown in Fig. 1. The plants were lifted and placed on the field roadway. Some of the soil in the original sod dropped off, but enough remained to hold these plants upright in a strong wind.

EFFECT OF DEPTH OF CUTTING UPON UPRIGHT POSITION OF THE PLANT

There are at least two factors determining the upright position of the plants after the roots have been cut. One, already discussed, is the wilting over of the plant with the sod remaining in its normal position. The other is the overturning of the sod and the plant with it. This latter factor would seem to depend mainly on the depth of cutting. In these tests many plants were overturned at the time of cutting. No plant was observed to remain upright if cut less than 2½ inches below the surface, excepting a few which, because of excessive amount of space (generally at the ends of the rows), had produced many tillers and a large crown. These sometimes were in such balance as to remain upright. No plant was observed in any variety with sod overturned where the cut was at least 5 inches below the surface.

By examination of the ramification of the roots, it was observed that they did not start to extend markedly to the side until about 3 inches below the surface, i. e., until they were through the mulch of cultivated soil. Below that depth they were observed to extend at all angles beneath the horizontal. With an increased depth of cut, therefore, there will be an increased volume of soil in the sod holding the plant upright, due not only to increased depth but to increased width as well. The roots are an important factor in holding the soil together in a sod of sufficient weight to hold the plant upright after the roots have been cut. Thus the well-known principle of the balancing toys, also used in the "loaded bottom" or "self-righting" type of salt and pepper shakers, is here utilized to keep the plant in an upright position. With most soils a sod a foot square and 6 inches deep should weigh about 40 pounds. This seems ample in weight to keep the sod in an upright position against any force applied to the plants to tip them over which at the same time would not break or bend the stalks of the plants themselves. Fig. 2 shows the function the sod plays in holding the plants upright. In applying this principle to the fullest it is probable that a blade bowed down in the center even more than those described above would be more efficient in keeping the plants upright.

EFFECT OF SPACING ON YIELD

In order to utilize this system of harvest (at least with the taller-growing varieties), it would be necessary to widen the rows somewhat. Trials were conducted during 1925 with the Heileman Dwarf and Double Dwarf milos, both with and without irrigation, in rows 42 inches and 84 inches apart. Five plats, each of four rows per plat, on non-irrigated and five rows per plat on irrigated land, were planted to each variety in each treatment. The center two or three rows were harvested for yield. Higher yields were secured from the wider spacings with both varieties where grown without irrigation, but the opposite was true where three irrigations were given during the growing season. According to Martin,[5] in the Great Plains region, spacing of the rows of grain sorghums double the normal distance has given practically as good yields of grain as with the normal spacing. In the following crop, however, land where the wider spacings were used has yielded from 3 to 4 bushels of wheat per acre more than where the normal spacing was used.

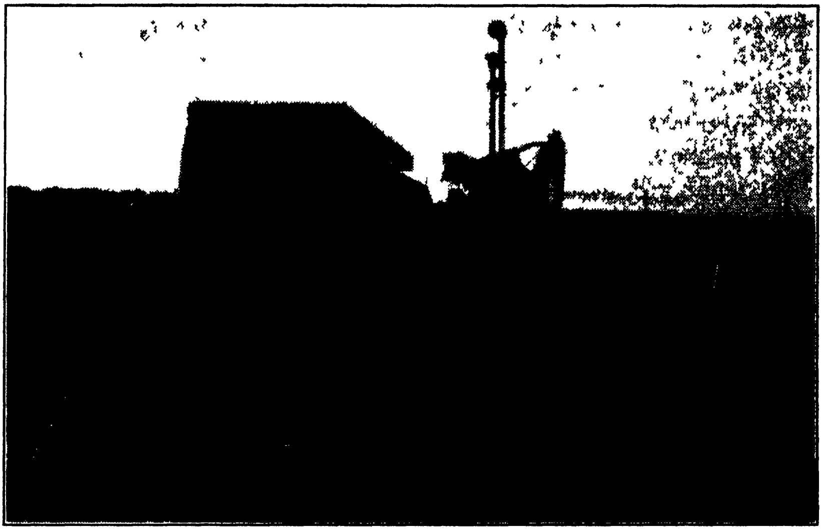

FIG. 3.—Rear view of a "combine" threshing Double Dwarf milo whose roots had been cut ten days previous. A few heads which were missed may be seen behind the machine. Appropriate devices on the "header" should materially reduce loss from this cause.

Rothgeb[6], working at the federal station at Amarillo, Texas, found that in practically all cases higher yields were secured from the 7-foot rows in unfavorable seasons, while the 3½-foot rows yielded at a higher rate in favorable seasons. Seiglinger[7], working at another federal station (Woodward, Oklahoma), reports figures from which it may be computed that spacing rows 88 inches apart instead of the normal 44 inches caused an average annual loss in yield of 2.0 ± 1.2% for Dwarf Yellow milo and 15.7 ± 0.5% for Sunrise kafir. A further discussion of this point is beyond the scope of this paper. Suffice it to say, that empirical results so far obtained indicate that under certain conditions wider spacing of rows will give higher yields, and under others the normal spacing will produce the higher yield.

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[5] Private conversation in 1925.

[6] Cultural experiments with grain sorghums in the Texas Panhandle. U. S. D. A. Bul. 976. 1922.

[7] Grain sorghum experiments at the Woodward Field Station in Oklahoma. U. S. D. A. Bul. 1175. 1923.

In a four-row plat of Double Dwarf milo, planted at 42 inches, the roots of the first and third rows were cut by straddling the second row, and those of the second and fourth by straddling the third. Even with a tractor and cultivator clearance of hardly 11 inches, less than 20% of the stalks were knocked down to the ground, though some seeds were stripped from the heads. Though this method is not to be recommended, it indicates what might be done with the Double Dwarf milo where the cultivator frame would be arched over the center row and would be pulled by some tractive power with a clearance of at least 24 inches.

HARVESTING WITH A "COMBINE"

All together but one-fifth of an acre (all being the Double Dwarf milo grown with irrigation) was actually harvested with a "combine," since the yields were desired by a more accurate method than could be obtained with this equipment. By harvesting with a stubble of 2 to 3 inches, between 90 and 95% of the heads were secured. If the guards of the sickle-bar, where they curve toward the ground, had been longer, or if pea-vine lifters had been attached, this percentage probably would have been increased. Fig. 3 gives a rear view of the "combine" in operation.

DISCUSSION

THE IDEAL HARVESTING SYSTEM

Undoubtedly, the easiest and cheapest way to harvest the grain sorghums for threshed grain would be to "pull into" the field with a "combine" and thresh the standing crop. Under very special conditions this has been done satisfactorily. Students from the grain sorghum belt of Texas have told the writer of the use of this method where killing frosts occur early enough in the fall to allow the plants to dry out before winter. Occasionally, growers of the early-maturing White Durra variety in California find their crops in such condition in the fall that this method may be used satisfactorily. However, many times where this has been tried loss of grain from heating has resulted, or else the growers have found it necessary to send the grain to the commercial dryers, where the percentage of moisture is lowered within safe limits at a cost varying from $3 to $5 or more per ton, depending on location, size of lots dried, etc.

It would be desirable to breed a variety of grain sorghum which in addition to the other desirable characters would dry out in the advancing fall weather as the grain filled. This would largely solve the problem. But the indeterminate nature of the plant's growth and its tenacity of life do not hold out much hope except where grown under especially favorable conditions.

The next best scheme which has come to the writer's attention is first to cut the roots of the plants as described in this paper and, after allowing the plants to dry out thoroughly, to use the "combine." This method would have so many advantages over any of the hand-heading, binding, or machine-heading methods which have been worked out heretofore that its possibilities should be examined carefully.

FURTHER EXPERIMENTATION

To take full advantage of the possibilities of this system of grain sorghum harvest, further experimental work should be done. This work largely divides itself into two phases, *viz* , one the perfecting of the mechanical equipment and the other the perfecting of the plant, both to fit better the requirements of the system. In the case of the needs of experimentation in regard to equipment, it would seem that for most conditions these could be met by better design and manufacture of the cutting knives and the cultivators themselves. In meeting the needs of this system in the other direction plants should be secured either through selection or breeding, which in addition to the desirable characters now possessed by them would be able to stand upright without wilting to the ground after the roots have been cut.

Under conditions where wider spacings would give higher yields or yields not materially less than normal plantings, it would seem that promising material is at hand in some of the varieties mentioned earlier in this paper. Where wider spacing gives yields less than at the normal distance, such loss might be materially cut down by leaving out every third row in a field planted with the normal distance between rows. This could be accomplished by cultivating out every third row while the growth was young. A better way would be to lengthen the marker bar of the planter by the normal distance between rows, thereby making the planting easier and eliminating the necessity of cultivating out each third row. In fact, where upright-growing varieties and a narrow (50 inches or less) tractor are used, the wider distance between the rows could be cut down to 66 inches (5½ feet), allowing meanwhile 6 inches on each side for manipulation of the tractor and 4 inches for the width of the space occupied by stalks in the row.

But under growing conditions where the normal width of plantings gives highest yields, this method should prove but temporary. It is barely possible that a horse-drawn, one-row root-cutter could be worked out for the dwarf varieties of upright-growing grain sorghums, such as the kafirs, where these are planted at the normal distances between rows. In this case the horses would go down on either side of the row being cut. The cutting blade would be continuous, from the cultivator frame on one side of the row to the frame on the other. The frame itself would be arched over the row. The whole picture works out fairly clearly except as to the way the eveners would be attached. However, the progress across the field would be slow by the use of such an implement. Where it was desired to do the work faster than could be accomplished with the one-row root-cutter, recourse should be made to tractor-drawn implements and extra dwarf varieties. If 24 inches were the maximum economic clearance that it would seem advisable to work out for tractor and cultivator frame, it seems as if characters which are now distributed among several varieties would be useful if combined by breeding into one variety. How well a plant of the short stature of the Double Dwarf milo, the erect stalks and heads of the kafirs, the feteritas, or White Yolo, and the ability to yield of the highest yielding strain of the region would fit into such a system of harvest!

ESTIMATION OF COST OF ROOT CUTTING

As a basis for computing costs, a rate of $25 per day of eight effective hours of work in the field has been taken as covering all costs, including fuel, interest, depreciation, repairs, and labor, for both tractor and cultivator. It is assumed that the tractor travels at 3 miles per hour, with a loss of 10% of the speed due to turning at the ends of rows, and that the roots of two rows are cut completely with one trip across the field. With rows spaced 84 inches apart this would give a cost of 68 cents per acre for cutting. Where the distances between rows were different, i.e., where they were 84 inches, 42 inches, etc., respectively, the estimated cost per acre would be 91 cents. Where the 84-inch spacing could be cut down to 66 inches, the cost would be $1.06. Where a short-growing variety, such as the Double Dwarf milo, was grown at the normal distance of 42 inches and where root cutting was accomplished by straddling one row and cutting one on either side of it, the estimated cost per acre would be $1.37. If in this last case the roots of the straddled row were also cut, i.e., if three rows were cut at once, the estimated cost per acre would be 91 cents.

Though $25 per day is considered by the writer more than ample to cover the complete per diem costs of tractor and implements, in case it should run higher, as it might very well do on heavier soils than those used in these tests, the costs would be proportionately higher. On the other hand, as will undoubtedly be the case under most conditions, if this amount is too high, the actual costs will be proportionately lower than these estimates.

Where a comparison is made of the relative costs of the system of root cutting followed by harvesting with a "combine" as against the system of "combining" first, followed by shipment to the driers, the figures presented so far do not give the whole picture. Chargeable to the latter system, in addition to the service charge of $3 to $5 or more per ton, are the following: (a) Cost of handling the excess moisture in the grain both on the farm and in freight; (b) where sacks are used, the cost of the extra sacks required to contain the damp grain; and (c) the risk of loss through heating if the moist grain is delayed for any reason in reaching the drying process.

Adams[8] gives $5.50 per acre as the cost of hand cutting of heads. This does not include hauling and "feeding" to the thresher. In addition is the condition the heads may be in in case of rain, unless covering is provided at extra expense. Root cutting, followed by harvesting with a "combine," when developed to its fullest efficiency, seems to offer the best possibilities of reducing the cost and difficulties of harvesting the grain sorghums over a great part of the grain sorghum area, and may even be a factor in extending the use of this excellent crop to greater areas. Any material increase in the acreage of this crop is not possible, however, without our being more forcefully confronted with another great problem of grain sorghum growing, which as yet remains unsolved, at least economically. This is the depression of yield of crops, especially small grains, following the growth of sorghums.

SUMMARY AND CONCLUSIONS

1. The difficulty of harvest seems to be one of the important reasons why grain sorghums are not more widely planted.

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[8] *In* Supplement No. 1 to "Farm Management Notes." Ed. 7. 1920. Distributed by the Associated Students' Store, Berkeley, Calif.

2. Root cutting, preparatory to harvesting with a "combine," has many theoretical advantages over systems of harvest now used.

3. Root cutting of grain sorghum plants was done with heavy horizontal blades attached to a heavy orchard cultivator and running beneath the crowns of the plants.

4. Where all of the roots were cut at 9 inches or less from the surface, the plants dried out rapidly except when irrigated immediately afterwards.

5. The plants which did not remain upright after the roots had been cut went over from two causes. In one case, the sod, consisting of the roots and the soil held in a large lump by them, was overturned. In the other case, the plants wilted down with the sod remaining in its normal position.

6. No plant whose roots were cut at least 5 inches from the surface went down due to the overturning of the sod. Only a very few plants remained standing when cut at 2½ inches or less from the surface. This is related to root ramification and weight of soil in the sod.

7. The characteristic of wilting to the ground seems to be a varietal one. In limited tests six varieties did not wilt down.

8. Conditions exist where planting at double the normal distance between rows gives higher yields of grain than at the normal (42-inch) distance. Under other conditions the reverse is true.

9. In harvesting with a "combine" after root cutting, between 90 and 95% of the heads were secured. Minor attachments could increase this percentage.

10. Work along two major lines of experimentation will be necessary to develop this system to its highest point of efficiency. One is to perfect the knives and supporting equipment; the other is the selection or breeding of strains or varieties that in addition to other desirable characters will not wilt to the ground after the roots are cut.

11. From the estimated and actual costs of the "root-cutting-combined-harvester" system as against the other systems of grain sorghum harvest now in use, this system seems to be more economical in cost of harvest than any except "combining" the standing crop without subsequent drying. Danger of loss from heating following the use of the latter system, however, prevents any but its very limited use.

EFFECT OF COLOR OF SEED, OF SCARIFICATION, AND OF DRY HEAT ON THE GERMINATION OF ALFALFA SEED AND OF SOME OF ITS IMPURITIES[1]

George Stewart[2]

The color and the plumpness of alfalfa seed greatly influence its market value. It is generally accepted that bright, plump seed of an olive-green color is better than discolored seed of any sort. Lack of information as to just how much better it is, and wherein this superiority lies, was the circumstance which gave rise to the studies here reported. Between 1921 and 1925 a rather large number of seed studies were conducted, chiefly in an incidental manner, on which account the work has been spread over a longer period than might otherwise have been necessary.

The presence of dodder seed (*Cuscuta* sp.) also greatly influences the selling value of commercial alfalfa seed. Its presence is almost entirely due to careless cultural methods, but it does nevertheless occur in seed, and once there the large-seeded variety cannot be economically removed with completeness by any known method. The seeds of Russian thistle and of Atriplex tumbleweed are also both prevalent. The possibility of killing these weed seeds with dry heat of such a degree that the alfalfa seed is uninjured thereby is also considered in a preliminary manner.

EFFECT OF COLOR OF ALFALFA SEED

PREVIOUS STUDIES

Certain phases of the relationship of seed color to germination strength were observed in Colorado previous to 1896 by Headden (5)[3] who tested the germination of different qualities of alfalfa seed. Prime seed germinated from 93 to 99% and screenings of first quality from 55 to 79% as compared with about 38% for both second and third quality screenings. The number of prime seed to the gram was between 450 and 500.

At Iowa it was reported by Miller and Pammel (9) that large alfalfa seed gave more vigorous plants than did small alfalfa seed. The experimental evidence, however, was too meager to be conclusive.

Pammel and Buchanan (10) shortly afterward observed a general difference between plump and shrunken alfalfa seed germinated in

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[1] Contribution from the Department of Agronomy, Utah Agricultural Experiment Station, Logan, Utah. Received for publication April 21, 1926.

[2] Agronomist.

[3] Reference by number is to "Literature Cited," p. 760.

March and the following November, but this was also based on very meager evidence as only 100 seeds were used in the November trial.

In tests in Kansas (13) it was found that in 21 samples of discolored and immature alfalfa seed, the germination ranged from 39 to 80%, with the average about 65%. Compared with these, five high-grade samples germinated 98%; while the poor seed picked from the good samples germinated approximately 70%.

Similar results were obtained by McCready (8) in Canada by germinating 10 random samples from a large number that had been secured for purity tests. One hundred seeds were sown in each test, making 1,000 seeds of each quality. Bright, plump seed germinated 82.5% and established 71% of the plants. The same figures for dull, plump seed were 55 and 37% and for shrunken seed 29 and 26%, respectively.

The results of this Canadian test may be accurately described in the words of True, *et al* (12) who, in discussing the Nevada purity tests, said "the presence of either brown or green seeds lessens the value of alfalfa seed from a commercial standpoint." True also observed that from brown seed many weak sprouts "appeared between the blotters."

An Australian test yielded almost identical results, giving 92% germination for yellow seed but only 44% for brown.

In addition to the few and not very adequate tests with alfalfa seed, two tests with red clover seed deserve mention here on account of their bearing on the problem treated in this paper.

In Germany, Kajanus (6) collected 15 samples of red clover seed, each sample being taken from a single plant. He divided each lot of seed into violet, yellow, and brown, and picked out 200 of the large, perfect seeds of each of the three sorts. These were weighed and germinated. In his Table 4 he shows that the violet seeds were heavier than either the yellow or the brown, which were about equal in this respect. In germination the violet and yellow seeds were about equal and exceeded the brown by about 10%. Observation of the speed of germination showed that violet seed germinated the quickest and brown seed the slowest.

Dymond (4) reports that of the red clover seed coming to the Dominion Seed Laboratory at Ottawa for purity test purple seed was slightly more prevalent than yellow. Yellow seed gave a somewhat higher percentage of germination and more hard seeds than did the purple. Brown seeds were lower in germination and contained only a small proportion of hard seed, whereas green seed was lowest of all in germination and highest of all in hard seed. The germination of the yellow and of the purple seeds was about 80 to 82%. The brown and the green seed germinated 40 and 35%, respectively.

EXPERIMENTAL

In 1920 somewhat more than 200 samples of alfalfa seed were obtained from the commercial lots being marketed by the growers of Millard, Emery, and Duchesne-Uintah Counties, Utah. About half of these were composited and thoroughly mixed into a stock sample from which were drawn all the seed fractions and check lots used in the experiments herein reported.

Bulk lots of seed were not used. In every case seven fractions of various colors and plumpness were compared, except in the case of checks which consisted of the same seed unseparated. The seed fractions were as follows:

1. True color: Bright yellow with a tinge of olive green; seed plump.
2. Light green: Enough green to be perceptible; seed plump.
3. Light brown· No yellow or green visible; seed plump.
4. Dark green. Distinctly dark green in color; seed plump.
5. Dark brown: Distinctly dark brown in color; seed plump.
6. Shriveled green.
7. Shriveled brown.

Checks: Unseparated seed.

When a test was begun the whole stock sample was run several times through a Boerner sampler and mixer to insure thorough mixing. A small amount was split off for the test and the remaining part put away till another test was to be run when it was again treated as described. The small quantity of seed split off was always more than large enough to supply checks and color fractions. When checks were used, they were obtained by splitting off about 20% of the quantity, the remaining 80% being separated by hand into the seven color fractions listed above. Small vials were preserved throughout the test as standard fractions. No effort was made to get more than about 50 to 60% of the seed into the fractions, the residue being discarded at once so as not to influence further separations.

These tests on the germination power of the various color fractions of alfalfa seed fall into two classes, *viz.*, (a) earlier tests in which no checks were used, the color fractions being compared only with themselves, or (b) later tests in which the value of the fractions are compared not only with themselves but with the unseparated seed used as checks.

The first experiment, reported in Table 1, was a trial to study the difference between the ordinary blotting paper germination and one in which the sprouts were required to come up through about ⅜ inch of sandy loam made by mixing thoroughly about half each of Greenville silt loam and sand from Lake Bonneville deposits. Counts were made and the sprouted seed removed on the third, the sixth, and the ninth days and the sum taken as the total germination. In the blotting paper test, counts were made of strong, weak, and moldy sprouts. In the sand test, strong and weak sprouts only were counted.

Table 1 shows a considerably higher germination when the seeds were germinated between blotting papers than when they were made to come up through ⅜ inch of moist sandy loam soil. Bright, true-colored seed germinated 69% between blotters, but only 59% came up through the ⅜ inch of loose soil. The discolored seed suffered much more heavily in the sand and approximately in proportion to the degree of discoloration. True-colored seed did 87% as well in sand as between blotters; light brown and dark green seed did 67 and 64% as well, respectively; but light green seed did only 50% as well. The more badly discolored and shrunken seed suffered still more seriously, shriveled green being the poorest with only 17% as many coming up through the soil as germinated on blotters.

The wide disparity between the percentage germination on blotters and the percentage emerging through a thin layer of moist and loose sandy loam kept in the best possible condition causes one to wonder just how valuable the ordinary laboratory germination tests are after all. Many other previous tests had given similar differences, but unfortunately the exact data were not taken.

After considering the data reported in Table 1, it was thought that

TABLE 1.—*Percentage germination of alfalfa seed between wet blotters and percentage of plants establishing themselves through 3/8 inch of moist, sandy loam soil.*[a]

Average of 10 repetitions of 50 seeds each for each figure. November, 1921.

Color	Germinated on blotter paper					Germinated in 3/8 in. sand		
	Strong	Weak	Moldy	Total	Hard	Strong	Weak	Total
	%	%	%	%	%	%	%	%
True color	68.7	0.1	0.2	68.8	31.0	53.2	5.8	59.0
Light green	64.8	2.6	5.4	67.4	27.2	31.6	2.2	33.8
Light brown	63.5	3.5	16.6	67.0	16.4	38.8	6.4	45.2
Dark green	47.6	5.4	36.8	53.0	10.2	32.8	1.2	34.0
Dark brown	35.8	4.2	24.4	40.0	35.6	14.6	—	14.6
Shriveled green	19.6	5.8	70.4	25.4	4.2	4.4	—	4.4
Shriveled brown	37.0	4.8	36.4	41.8	21.8	6.2	2.8	9.0

[a] D. E. Heywood, a student assistant, conducted most of the tests from which the data tabulated in Tables 1 to 6, inclusive, were taken.

the soil medium would in all likelihood more truely reflect field results. It was decided therefore to conduct the principal experiment trials in soil.

The soil medium after being thoroughly mixed was moistened and allowed to stand from 24 to 36 hours. It was then put into wooden boxes about 4 inches deep and filled to within an inch of the top. Moisture was maintained from the bottom by the wooden soil boxes being set in slightly larger metal boxes. Water was run into the metal box and entered the soil through holes in the bottom of the wooden boxes. Whenever any evidence of drying appeared, tap water was run into the metal box. The seeding was done in furrows 1½ inches apart and ⅜ inch deep. The rows were made crosswise of the box, which was about 16 inches in width, and 25 seeds were sown in each furrow. When several furrows had been sown they were covered with soil dragged in by a straight edge, after which the soil was slightly compacted. A wooden cover was used to reduce surface drying.

In all seven trials were run. The first three trials consisted of a row each of the color fractions, followed by another row of each, until all had been sown three to five times. Counts were made of each row and these added to get the total. In the fourth, fifth, sixth, and seventh trials, three adjacent rows of each color fraction were sown in a three-row block, and after all were sown they were repeated until there were three three-row blocks of each fraction. Table 2 gives a

TABLE 2.—*Summary of the numbers and the percentages of establishment of alfalfa seed of various colors in seven different trials.*

Sown in moist sand ⅜ inch deep, 1921–22.

	Number of plants established by test number								
Number of seed sown	1	2	3	4	5	6	7	Total	Average
in each separate	125	125	75	225	225	225	225	1,225	percentage
True color	75	81	52	161	142	152	134	797	65.1
Light green	70	77	44	138	135	127	129	720	58.8
Light brown	64	81	42	128	134	104	184	659	53.6
Dark green	55	70	38	104	101	84	103	555	45.3
Dark brown	42	60	28	91	109	100	86	496	40.5
Shriveled green	24	26	17	62	64	52	52	297	24.2
Shriveled brown	24	29	11	48	42	30	48	229	18.7
	Percentage of plants established								
True color	60.0	64.8	69.3	71.6	63.1	67.6	59.6	—	65.1
Light green	56.0	61.6	58.7	61.3	60.0	56.5	57.4	—	58.8
Light brown	51.2	64.8	56.0	56.9	59.6	46.2	46.2	—	53.6
Dark green	44.0	56.0	50.7	46.2	44.9	37.3	45.8	—	45.3
Dark brown	33.6	48.0	37.3	40.5	48.5	44.4	29.3	—	40.5
Shriveled green	19.2	20.8	22.7	27.6	28.4	23.1	23.1	—	24.2
Shriveled brown	16.8	23.2	14.7	21.3	18.7	13.3	21.3	—	18.7

summary of the data for these seven trials. Since these first seven trials were run without checks, they are kept by themselves and may be regarded as somewhat preliminary. They do permit of comparison of the color separates among themselves, however. This is likewise true of the data given in Table 3 in which are reported three other trials made the following July and not included with the seven December–January tests given above because they vary from these, showing about 3 to 12% higher establishment of plants in the various color separates.

TABLE 3.—*Germination of various color separates of alfalfa seed.*

Tests made in July, 1922.

	Germination on						Total	
	July 11		July 12		July 15		germination	
	No.	Percentage	No.	Percentage	No.	Percentage	No.	Percentage
Number of seed sown in each separate	125		125		75		325	
True color	85	68.0	88	70.4	51	68.0	224	68.8
Light green	86	68.8	79	63.2	49	65.4	214	65.8
Light brown	77	61.6	73	58.4	43	57.3	193	59.1
Dark brown	68	54.4	73	63.2	32	42.7	173	53.4
Dark green	63	50.4	62	49.6	39	52.0	164	50.7
Shriveled green	31	24.8	52	41.6	14	18.7	97	28.4
Shriveled brown	32	25.6	25	20.0	13	17.3	70	21.0

In Table 4 the data for the December–January and for the July germinations are brought together for comparison. The higher germination in July suggests that a study of germination at different times of the year might give interesting results, but these data are not held to be conclusive as to what results would be obtained.

As previously indicated, counts were taken on the third, sixth, and ninth days. This permits an arrangement of the data so as to study roughly the quickness with which germination (Table 5) occurred in the different color fractions, one as compared with the others, and December seedings as compared with those made in July.

Seeds from the true color, light green, and light brown fractions, as a whole, germinated somewhat more quickly than did the darker colored seed, whether plump or shrunken. July seedings gave less germination by the third day, but seemed to come more largely between the third and sixth days. This would have been even more marked had there been counts on the second day, as most of the three-day sprouts on July seeding germinated on the third day, whereas the December seedings began on the second day.

Two of the December tests, involving five rows each, were counted on the second, third, fourth, fifth, sixth, eighth, and tenth days. These data, as given in Table 6, indicate a rather decided tendency of the badly discolored seed to be slow in starting, except in the case of the shriveled green which is irregular here, for in other tests it also was slow.

TABLE 4.—*Comparison of winter (December) germination with summer (July) germination.*

Color	Winter Number of seeds sown	Winter Number germinated	Winter Percentage germinated	Summer Number of seeds sown	Summer Number germinated	Summer Percentage germinated
True color	,225	797	65.1	325	224	68.8
Light green	,225	720	58.8	325	214	65.8
Light brown	,225	657	53.6	325	193	59.1
Dark green	,225	555	45.3	325	164	50.7
Dark brown	,225	496	40.5	325	173	53.4
Shriveled green	,225	297	24.2	325	97	28.4
Shriveled brown	,225	229	18.7	325	70	21.0

TABLE 5.—*Relative speed of germination of the various color separates of alfalfa in December–January tests as compared with July tests.*

The figures given are percentages of the total number of seed that germinated.

Color of seeds	Germination on Third day Range %	Third day Average %	Sixth day Range %	Sixth day Average %	Tenth day Range %	Tenth day Average %
December–January Tests						
True color	63.4 to 89.5	77.9	9.2 to 36.6	19	1.3 to 6.7	3.1
Light green	55.1 to 85.2	75.2	14.1 to 44.2	23.9	0.7 to 2.6	0.9
Light brown	69 to 93.7	79.3	4.7 to 31	19.9	0.7 to 2.5	0.8
Dark green	63.1 to 80.8	70.5	21.4 to 31	25.7	2.9 to 7.9	3.8
Dark brown	42.8 to 81.8	61.9	16.3 to 57.1	31.9	1.5 to 18.3	6.0
Shr'v'l'd green	47 to 96.1	65.9	1.9 to 45.8	30.6	1.6 to 11.8	3.4
Shr'v'l'd br'wn	42.8 to 75	62.2	22.9 to 57.1	33.4	3.3 to 17.2	5.4
July Tests						
True color	37.6 to 64.8	54.4	34.1 to 56.5	43.3	1.1 to 5.9	2.3
Light green	15.1 to 67.1	42.4	31.6 to 74.4	53	1.3 to 10.5	4.6
Light brown	13.0 to 50.3	43	38.4 to 76.6	51.5	1.4 to 10.4	5.5
Dark green	4.8 to 64.1	37.4	33.3 to 87.3	61.3	2.6 to 7.9	4.6
Dark brown	5.9 to 56.2	37.1	40.6 to 85.3	58.4	1.4 to 8.8	4.4
Shr'v'l'd green	12.9 to 50	36.3	48.1 to 77.4	48.5	5.8 to 9.7	5.2
Shr'v'l'd br'wn	3.1 to 53.8	35.0	46.2 to 78.1	58.7	0 to 18.8	6.3

EFFECT OF SCARIFYING ALFALFA SEED

In order to find out the effect of scarification on these seed fractions, two experiments were conducted with alfalfa seeds scarified by means of an Ames scarifier run at 2,040 and at 2,885 revolutions, and

TABLE 6.—*Speed of germination of the different color fractions.*

The number of seeds germinating on a given day and the total percentage germinated up to and including that day, the total number that germinated being taken as 100.

Color fraction	Total number of seed		Germination on													
			2d day		3d day		4th day		5th day		6th day		8th day		10th day	
	Sown	Germinated	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
True color	200	133	40	30.1	62	76.7	22	93.2	1	93.9	1	94.7	5	98.5	2	100
Lt. green	200	121	24	19.8	72	79.3	18	94.2	4	97.6	1	98.4	1	99.2	1	100
Lt. brown	200	123	23	18.7	71	76.4	23	95.1	3	97.5	1	98.4	0	98.4	2	100
Dk. green	200	108	4	3.7	40	69.4	15	83.4	2	85.3	8	92.6	5	97.2	2	100
Dk. brown	200	88	7	8.0	24	53.4	18	73.8	6	80.7	6	87.5	9	97.7	2	100
Shriveled green	200	43	2	4.6	24	60.4	12	88.4	3	95.2	0	95.2	0	95.2	2	100
Shriveled brown	200	40	1	2.5	22	57.5	6	72.5	4	82.5	1	85.0	5	97.5	1	100

with unscarified seed. The unseparated bulk seed was run through the scarifier, and the separations were made afterwards by hand and compared with the color standards. When sufficient of each separate was obtained for a fairly large number of trials, three random samples of each color separate were counted and weighed. Table 7 shows these weights of random samples of three lots of 200 seeds each of the color fractions. The samples were taken after a thorough mixing and splitting in a Boerner sampler and mixer. The average weight and the relative weight are also shown.

True-colored and light brown seed were both heavier than the unseparated check; dark brown seed was approximately equal to the check in weight; while all the other separates were lighter in weight, the green in every case being lighter than the corresponding brown seed. This agrees with the opinion held by certain seedsmen that the green seed indicates immaturity, whereas brown seed indicates weather, sun, or frost injury—sometimes to fully developed seed and sometimes to seed only partly developed.

TABLE 7.—*Weights in grams of random samples of 200 unseparated alfalfa seeds (checks) and of 200 seeds of each of the seven color fractions.*

Seed fraction	First trial	Second trial	Third trial	Average weight	Relative weight
Checks (original unseparated seed)	0.3907	0.3669	0.3914	0.3828	100
True color	0.4400	0.4264	0.4374	0.4345	114
Light green	0.3611	0.3502	0.3683	0.3599	94
Light brown	0.4354	0.4162	0.4333	0.4250	111
Dark green	0.2843	0.2967	0.3004	0.2905	76
Dark brown	0.3638	0.4067	0.3578	0.3751	98
Shriveled green	0.2240	0.2286	0.2359	0.2295	60
Shriveled brown	0.2949	0.3063	0.2992	0.3001	78

The germination tests were conducted in the boxes and with the soil medium already described. The seeds were sown as in the previous trials, 25 seeds to the row with the rows run cross-wise of the 16-inch boxes. Each trial consisted of two rows, or 50 seeds, of each

TABLE 8.—*Number of plants established through 3/8 inch of sandy loam soil; 50 seeds of each color fraction sown for each trial under each treatment; arranged in germination classes according to frequency of germination obtained.*

18 trials.

Treatment and color fraction	Frequency of germination in germination classes									Mean	Percentage germination
	0–5	6–10	11–15	16–20	21–25	26–30	31–35	36–40	41–45		
Unscarified											
1. True color.......				1	1	6	10			29.7±0.69	59.4
2. Light green......				3	7	8				24.6±0.59	49.2
3. Light brown.....		3	5	6	2	2				15.6±0.87	31.2
4. Dark green......			6	8	4					17.4±0.64	34.8
5. Unseparated check				2	1	13	2			27.0±0.60	54.0
6. Dark brown.....	2	11	4	1						9.2±0.51	18.2
7. Shriveled green. .		7	5	5	1					12.8±0.71	25.6
8. Shriveled brown..	14	4								3.8±0.29	7.6
9. Unseparated check			2	2	3	6	7			28.7±0.89	57.4
Average (checks omitted)....										16.2±0.24	32.4
Scarified 2,040 revolutions											
1. True color.......					1		2	10	5	37.1±0.71	74.2
2. Light green......			1				7	10		35.3±0.87	70.6
3. Light brown.....		1		6	7	3	1			21.7±0.89	43.4
4. Dark green......		2	2	3	5	6				21.1±1.06	42.2
5. Untreated check..					3	13	2			27.8±0.47	55.6
6. Dark brown.....	1	1	8	6	2					14.3±0.79	28.6
7. Shriveled green...	1	6	5	4	2					13.3±0.90	26.6
8. Shriveled brown..	3	11	4							7.8±0.49	15.6
9. Untreated check..				2	3	6	7			28.0±0.75	56.0
Average (checks omitted)....										21.5±0.32	43.0
Scarified 2,885 revolutions											
1. True color.......							6	7	5	37.9±0.60	75.8
2. Light green......					2	4	6	5	1	33.1±0.78	66.2
3. Light brown.....			1	1	12	2	1	1		24.4±0.76	48.8
4. Dark green[a].....		3	7	3	2	1				13.9±1.09	27.8
5. Untreated check..				1	5	7	5			26.9±0.75	53.8
6. Dark brown.....		5	6	6	1					14.2±0.63	28.4
7. Shriveled brown..	1	12	4	1						14.2±0.58	28.4
8. Shriveled green...		3	9	5	1					9.1±0.47	18.2
9. Untreated check[b].				2	5	6	2			25.8±0.72	51.6
Average.......										21.0±0.13	42.0

[a] Only 16 trials.

[b] Only 15 trials.

color fraction. Checks were inserted after the fourth color separate and after the seventh. Each trial therefore consisted of a two-row block (50 seeds) of each color fraction and checks for the unscarified seed, and of two lots of seed scarified at a different number of revolutions with checks. The order of planting can be seen by referring to Tables 8, 9, or 10. None of the checks were scarified, not even for comparison with scarified color separates.

TABLE 9.—*Number of weak sprouts from various color separates of alfalfa through 3/8 inch of sandy loam soil arranged in weak-sprout classes according to frequency of weak sprouts obtained.*

50 seeds sown in each case; 16 trials.

Treatment and color fraction	Weak-sprout classes 0	1	2	3	4	5	6	7	8	9	10	Mean	Percentage weak
Unscarified													
1. True color......	4	4	5	2	1							1.4±0.19	4.6
2. Light green.....	3	4	5	3							1	2.1±0.42	8.0
3. Light brown....		2	8	1	4		1					2.7±0.22	16.5
4. Dark green.....	1	6	6	2			1					1.9±0.23	10.8
5. Unseparated ck.	4	3	5	2	2							1.7±0.20	6.0
6. Dark brown....	3	7	4	1	1							1.4±0.18	14.7
7. Shriveled green..		3	4	3	1	3	1				1	3.6±0.45	27.1
8. Shriveled brown	11	1	4									0.6±0.14	6.0
9. Unseparated ck.	4	4	3	3	1	1						1.8±0.25	6.0
Average (checks omitted)...												1.95±0.11	
Scarified 2,040 revolutions													
1. True color......	1	2	1	3	5	1	1	1	1			3.7±0.35	9.7
2. Light green.....		1	2	5		2	2	1	1	1	1	4.8±0.58	13.8
3. Light brown....		1	2	3	3	3	2	1	1			4.2±0.31	18.5
4. Dark green.....		2	2	4	5		1	1			1	4.2±0.62	19.1
5. Unseparated ck.	1	3	7	3	1	1						2.2±0.20	7.6
6. Dark brown....		2	6	4	3	1						2.8±0.19	18.4
7. Shriveled green..		3	4		4	3	2					3.4±0.29	24.8
8. Shriveled brown		5	6	3		2						2.2±0.21	26.5
9. Unseparated ck.	3	5	5	1		1				1		2.0±0.37	6.9
Average (checks omitted)...												4.1±0.15	
Scarified 2,885 revolutions													
1. True color......			2	1	4	3	4	1	1		3	4.6±0.28	11.9
2. Light green.....			2	1	2	1	4	2	1			6.1±0.47	18.4
3. Light brown....	1	1	1	2	4	2	2	3				4.1±0.36	16.8
4. Dark green.....	2	2	2	3	1	3	1	1			1	3.4±0.44	25.6
5. Unseparated ck.	3	5	5	2		1						1.5±0.22	5.5
6. Dark brown....		1	6	4	3	1	1					2.7±0.22	18.8
7. Shriveled green..		2	3	3	5	2		1				3.4±0.26	23.8
8. Shriveled brown		7	6	3								1.7±0.13	18.7
9. Unseparated ck.	1	3	2	5	2							1.8±0.22	8.5
Average (checks omitted)...												3.71±0.12	

In all, 18 trials were run and the total germinations for each of the 27 two-row blocks of each trial were recorded separately. These data are shown in Table 8 in frequency classes according to the number of times out of the total 18 a certain germination count was obtained. The mean number of seeds out of each 50 seeds sown is also given along with the probable error calculated for the 18 counts.

TABLE 10.—*Number of moldy sprouts from various color separates of alfalfa seed sown in 3/8 inch sandy loam soil, arranged in frequency classes according to the number of moldy sprouts obtained.*

50 seeds sown in each case; 16 trials.

Treatment and color fraction	Moldy-sprout classes 0	1	2	3	4	5	6	7	8	9	10	Mean	Percentage moldy
Unscarified													
1. True color.....	11	4		1								.6 ± .15	1.95
2. Light green.....	9	5	1		1							.7 ± .18	2.80
3. Light brown....	7	5	2		1	1						1.1 ± .24	6.71
4. Dark green....	8	6	2									.6 ± .12	3.41
5. Unseparated ck.	10	2	3	1								.7 ± .17	2.49
6. Dark brown....	12	3		1								.4 ± .13	4.21
7. Shriveled green..	6	4	3	1	2							1.3 ± .23	9.77
8. Shriveled brown	12	2	1									1.3 ± .10	3.00
9. Unseparated ck.	8	3	3	1								.8 ± .17	2.65
Average (checks omitted)...												.86 ± .068	4.94
Scarified 2,040 revolutions													
1. True color......	3	6	7									1.2 ± .13	3.15
2. Light green.....	5	6	2	1	1		1					1.4 ± .27	3.81
3. Light brown....	1	2	6	4	1		2					2.6 ± .27	11.45
4. Dark green.....	3	5	4	2	1				1			1.9 ± .32	8.63
5. Unseparated ck.[a]	6	6	4									.9 ± .13	3.12
6. Dark brown....	8	3	2	2				1				1.2 ± .31	7.89
7. Shriveled green..	1	7	7			1						1.6 ± .18	11.90
8. Shriveled brown	10	3	1	2								.7 ± .18	8.43
9. Unseparated ck.[a]	11	2	2		1							.6 ± .19	2.06
Average (checks omitted)...												1.51 ± .093	7.89
Scarified 2,885													
1. True color......	3	2	5		3	2	1					2.4 ± .34	6.23
2. Light green.....	3	1	1	3	3	1	3				1	3.6 ± .44	10.84
3. Light brown....	2	1	5	4	1	1	2					2.8 ± .30	11.47
4. Dark green.....	7	2	4	2		1						1.3 ± .24	9.77
5. Unseparated ck.[a]	7	5	2	2								.9 ± .18	3.31
6. Dark brown....	7	4	3	2								1.0 ± .17	6.94
7. Shriveled green..	5	2	5	3	1							1.6 ± .22	11.19
8. Shriveled brown	10	3	1	2								.7 ± .18	7.69
9. Unseparated ck.[a]	6	3	3	1								.9 ± .19	4.25
Average (checks omitted)...												1.91 ± 1.08	9.16

[a] Not scarified.

The mean percentage germination for each separate and a grand average for each of the three lots are also given.

Careful counts were kept of the weak seedlings that seemed healthy and of the ones that were moldy on emergence or became so immediately after. These two sets of data appear in Tables 9 and 10, grouped into frequency classes as in Table 8.

As in the previous tests, there is shown a germination difference between the color fractions. It is apparent that the bright-colored seed is significantly higher in established seedlings than in the checks, and that the checks are higher than the discolored seeds. Scarified seed gave significantly higher total establishment than did unscarified. High-speed scarification was no better than ordinary speed. The difference is strictly within the limits of probable error, except with dark green seed in which case high speed seemed to cause injury. This may be nothing more than an irregularity.

Examination of Tables 9 and 10 shows that there were more weak and more moldy seedlings from the scarified than from the unscarified seed. Seed of discolored fractions gave a higher percentage of weak and also of moldy seedlings than did the bright-colored seed.

In Table 11 is given a summary of the data presented in Tables 8, 9, and 10 with the data for the two scarification treatments reported together and compared with the normal unscarified seed. In total germination the scarified seed as compared with the normal unscarified was 132:100. This advantage of scarification was partly offset by the higher percentages of weak and of moldy seedlings from the scarified seed. Taking the germination of the checks as 100, the number of weak seedlings in the scarified compared to the number

TABLE 11.—*Summary table, showing relative values of various color fractions of alfalfa seed in normal (untreated) seed and in scarified seed.* Germination of the untreated checks is taken as 100.

Color fraction	Total		Weak		Moldy		Net—Healthy and vigorous			
	Normal	Scarified	Normal	Scarified	Normal	Scarified	Normal	Scarified	Mean	Relative
Unseparated check	55.8	54.3	3.5	3.7	1.5	1.6	50.8	48.9	49.5	100
True color	59.4	75.0	2.8	8.3	1.2	3.6	55.4	63.2	60.5	122
Light green	49.2	68.4	4.2	10.9	1.4	5.0	43.6	52.5	49.5	100
Light brown	31.2	46.6	5.4	8.3	2.2	5.4	23.6	33.9	30.5	62
Dark green	34.8	35.0	3.8	7.6	1.2	3.2	29.8	24.2	26.1	53
Dark brown	18.2	28.5	2.8	5.5	0.8	2.2	14.6	21.0	18.9	38
Shr'v'l'd gr'n	25.6	27.5	7.2	6.8	2.6	3.2	15.8	17.5	16.9	34
Shr'v'l'd br'wn	7.6	16.9	1.2	3.9	0.6	1.4	5.8	11.6	9.7	20
Mean	32.3	42.6	3.9	7.3	1.4	3.4	26.9	32.0	30.3	61
Relative	100	132	12	24	4	11	84	97	94	

in the unscarified was in the ratio of 24:12. The ratio of moldy seedlings in the scarified to those in the unscarified was 11:4. The net germination of vigorous, healthy sprouts is 97% to 84% in favor of the scarified seed.

EFFECT OF DRY HEAT

Although there is a rather extensive literature regarding the effect of heat on seeds of various sorts, Bresoala (2, 3) is the only one who has investigated the influence of dry heat on the germination of seeds of alfalfa and of dodder. He reported that dodder seed could be killed by heating at 75°C. for an hour without injuring the alfalfa seed. Since his paper is rather inaccessible being available only in Italian, his most important data are summarized in Table 12.

In December, 1921, some preliminary heating experiments, the data of which are shown in Table 13, were run to check Bresoala's data.[4] It was at once apparent that the temperature and duration of heating given in the Italian experiments could not be accepted in Utah for Utah-grown seed. The range of temperature and of duration of heating was extended somewhat, the heating being done in a good soil oven. Obtainable dodder seed could not be made to germinate well enough to get a viability test on the seed of this plant, but seeds of Russian thistle (*Salsoli*), mustard (*Brassica* sp.), and

TABLE 12.—*Percentage of germination obtained by Bresoala when he heated seeds of alfalfa, two clovers, and two dodders at various temperatures for various periods of time.*

Tests made in Italy in 1919.

Temperature	Time heated in hours	Percentage germination for *Medicago sativa*	*Trifolium pratense*	*Trifolium repens*	*Cuscuta arvensis*	*Cuscuta trifolii*
Check	0	79.0	94.0	57.5	47.4	36.3
60°C.	½	89	94	71	12	21
	1	91	86	64	9	27
	2	89	88	59	6	23
65°C.	½	93	86	65	9	26
	1	78	82	73	2	17
	2	81	88	71	0	7
70°C.	½	86	90	71	1	16
	1	84	88	61	0	16.5
	2	10	10	12	0	5
75°C.	1/6	84	86	59	34	36
	½	84	88	63	0	25
	1	76	78	67	0	23
80°C.	1/6	36	12	6	1	2
	½	46	8	16	0	13

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[4] D. C. Tingey, then student assistant in the Department of Agronomy, made these tests.

green foxtail (*Setaria viridis*) were tried in a preliminary way. It was found that heating up to 80°C. for two hours increased the germination of seeds of mustard (*Brassica*) and of green foxtail (*Setaria*), but caused a perceptible decrease in the percentage germination of Russian thistle (*Salsoli*). Most striking of all, however, was the increased germination of alfalfa seed after being heated. There were increases in the percentage germination of alfalfa seed varying from 18 to 39, principally at the expense of the "hard" seed.

TABLE 13.—*Effect of dry heat on the percentage germination of alfalfa seed and on the number of "hard" seed left.*

Average of closely corresponding duplicate trials made in 1921.

Lot of seed and treatment	Heated at 75°C.		Heated at 80°C.	
	Time—1 hour	Time—1½ hours	Time—1 hour	Time—2 hours
Millard 45A				
Heated......	85.5	88.5	94.0	94.5
Unheated....	65.0	70.5	64.0	67.5
Increase...	20.5	18.0	30.0	27.0
Hard Seed				
Heated......	5.0	1.0	4.5	3.5
Unheated....	21.0	22.0	28.5	31.0
Decrease...	16.5	21.0	24.0	27.5
Emery 47B				
Heated......	79.5	90.0	93.5	92.0
Unheated....	53.5	55.5	56.0	52.5
Increase...	16.0	34.5	37.5	39.5
Hard Seed				
Heated......	12.0	9.0	5.5	7.0
Unheated....	41.0	42.0	40.0	46.0
Decrease...	29.0	33.0	34.5	39.0
Duchasne 51C				
Heated......	92.0	98.0	92.5	98.5
Unheated....	69.0	65.5	63.5	68.5
Increase...	23.0	32.5	29.0	30.0
Hard Seed				
Heated......	1.5	1.5	5.5	1.0
Unheated....	27.5	32.0	35.0	29.0
Decrease...	26.0	30.5	29.5	28.0

In 1923, as part of his master's thesis, Staker (11) heated seeds of alfalfa and of common contaminating weeds in a bath of circulating hot oil with an electric heating device and a thermostat control. The seeds were heated in long-necked sugar-flasks with the bulbs held several inches below the surface of the oil. The killing point of alfalfa seed was found to be about 93°C. with a half hour's heating and about 90°C. with four hours' heating. Although Staker's test is only preliminary, there is little doubt that heat begins markedly to depress the germination of seed of dodder, Russian thistle, and Atriplex tumble-weed well below the killing point of alfalfa seed.

Tests of the effect of heat on the color fractions of alfalfa seed were also made. The seed lots used were from color fractions carefully prepared for the germination tests reported in Tables 8, 9, and 10. Heating up to 85°C. for four hours caused an increase in the percentage germination of the true-colored, light green, and the unseparated check seeds, but caused a decrease in the percentage germination of the seed of the dark green, dark brown, shriveled green, and shriveled brown fractions.

Heating tests were repeated in 1925 with the same sort of heat control. This was found to be very uniform in its effect. As it was

TABLE 14.—*Effect on germination of dry heating the color fractions of alfalfa seed at various temperatures for four hours.*

Germinated on wet blotting papers, average of five tests of 100 seeds each, 1925.

Color fraction and treatment	Germination after heating at				
	60°C. %	70°C. %	80°C. %	85°C. %	90°C. %
True Color					
Heated	94.1	94.6	92.7	96.8	76.9
Unheated	70.3	71.2	68.4	68.0	73.2
Light Green					
Heated	91.5	94.0	95.3	89.9	55.5
Unheated	64.4	69.3	70.0	65.8	72.5
Light Brown					
Heated	36.7	39.6	37.7	30.0	20.6
Unheated	35.2	34.1	33.9	31.7	29.5
Dark Green					
Heated	60.9	53.5	28.0	19.6	3.9
Unheated	42.8	48.2	47.0	43.1	39.0
Dark Brown					
Heated	34.4	37.5	31.9	13.2	7.4
Unheated	37.5	41.0	41.5	43.2	39.6
Shriveled Green					
Heated	35.5	34.6	43.8	17.3	4.4
Unheated	34.5	34.0	34.0	43.3	45.0
Shriveled Brown					
Heated	32.2	17.5	22.7	14.8	6.0
Unheated	30.1	25.1	24.0	28.1	25.2
Check, from bulk sample					
Heated	69.0	81.4	93.6	87.4	58.3
Unheated	58.1	54.9	55.6	70.0	53.9

not felt that Staker's single test trials were adequate, the color fractions of alfalfa seed were repeated five times, the average being reported in Table 14. These results confirm Staker's data and show that heating markedly reduces the germination of badly discolored seeds of alfalfa.

Seeds of various weeds that commonly contaminate alfalfa seed were heated, the whole test being in triplicate except in the case of dodder (*Cuscuta*) which was only a single test. The results are given in Table 15.

TABLE 15.—*Effect of dry heat on the seeds of various weeds commonly found in Utah-grown alfalfa seed.*

Germinated on wet blotting papers, average of three tests of 100 seeds each, except *Cuscuta* which was a single test, 1925.

Kind of seed and treatment	Germination after heating at			
	70°C.	80°C.	85°C.	90°C.
	%	%	%	%
Russian thistle (*Salsoli tragus*)				
Heated	95.3	90.7	21.0	7.3
Unheated	97.7	98.7	95.0	96.3
Atriplex tumbleweed (*Atriplex hastata*)				
Heated	90.7	16.3	9.0	0
Unheated	95.0	94.7	95.3	93.3
Redroot pigweed (*Amaranthus retroflexus*)				
Heated	100	100	97.3	94.7
Unheated	96.7	100	99.3	95.3
Green foxtail (*Setaria viridis*)				
Heated	100	100	100	100
Unheated	100	98.7	100	100
Hare's ear mustard (*Conringia orientalis*)				
Heated	92.0	98.3	98.7	96.7
Unheated	99.3	93.3	95.0	95.3
Dodder, large-seeded (*Cuscuta* Sp.)				
Heated	7	0	1	0
Unheated	8	11	9	7
H_2SO_4	41	36	31	23

Staker's results were confirmed in that dodder, Russian thistle, and Atriplex tumble-weed were practically eliminated by heating to 85°C. for four hours. Germination of green foxtail (*Setaria viridis*), redroot pigweed (*Amaranthus retroflexus*), and hare's ear mustard (*Conringia orientalis*) was not at all decreased by heating to 90°C. Table 15 shows the averages for the triplicate tests.

The data given are conclusive evidence that whatever it is that causes seed to be hard is affected by heating. There is no means of telling from the data whether some volatile substance is driven off or whether the seedcoats are affected in some other way. A gummy odor given off during heating suggests a volatile substance.

SUMMARY

In this treatise attention is called to the general knowledge that discolored alfalfa seed is inferior to bright-colored seed. There was, however, no previous accurate information as to the degree to which discolored seeds of various sorts lowered the agricultural value of alfalfa seed.

Alfalfa seed was graded into seven color separates and the powers of each to germinate on blotters and to establish plants through ⅜ inch of sandy loam soil were carefully measured.

A considerably smaller number of seedlings reached the surface when the seeds were sown ⅜ inch deep in sandy loam than the number of seeds that germinated between wet blotters. Taking the germination between blotters as 100 for each color separate the following relative values were obtained:

	Germinated between blotters	Came through ⅜ inch soil
True color..........	100	87
Light green.........	100	50
Light brown........	100	67
Dark green.........	100	64
Dark brown........	100	37
Shriveled green......	100	17
Shriveled brown.....	100	22

It is possible that the lower relative value of light green seed in soil is due in part to chance, since only 10 counts were made.

The discolored seed seemed also to germinate more slowly than did the brighter colored fractions.

When compared to unseparated bulk seed, true-colored and light brown seeds were heavier, light green seed was about equal in weight, and all discolored seeds were noticeably lighter. Green seeds of any shade were lighter than the corresponding brown seeds.

When the unseparated seed is taken as a base, the relative germination in soil of the color fractions are as follows:

1. Unseparated seed, check....................................	100
2. True color, bright olive green..............................	122
3. Light green...	100
4. Light brown..	62
5. Dark green...	53
6. Dark brown..	38
7. Shriveled green..	34
8. Shriveled brown...	20

Scarified seed gave a higher percentage germination than did unscarified seed in the proportion of 132:100. Careful counts of weak seedlings and of moldy sprouts showed these to be more prevalent in the scarified seed. The following relative figures bring out these relationships:

	Scarified	Untreated
Total germination	132	100
Weak seedlings	24	12
Moldy sprouts	11	4
Net, healthy and vigorous	97	84

From a relatively few but carefully controlled tests it seems that dry heat up to 85°C. applied during a period not to exceed four hours increased the germination of alfalfa seed by causing most of the hard seed to germinate. Discolored alfalfa seeds were injured considerably at much lower temperatures than were bright, mature seed.

Of the weed seeds likely to be found in Utah-grown alfalfa seed, the percentage germination of *Setaria* and *Conringia* was not reduced when the seeds were heated for four hours at 90°C. It seems probable that dodder and Russian thistle seed might be largely or entirely eliminated from alfalfa seed by the application of dry heat. No attention, however, has been given to the devising of commercial apparatus.

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FACTORS FOR COLOR OF ALEURONE AND ENDOSPERM IN MAIZE[1]

H. K. Hayes and H. E. Brewbaker[2]

As a result of intensive studies of inheritance which have been conducted for the most part since 1910, a good start has been made in the determination of chromosome group relationships in maize. Factors for aleurone color have been found in three different linkage groups. Much of the credit for the extensive cooperative studies of linkage investigations with maize is due to Dr. R. A. Emerson of Cornell University who, with his students, has made a large part of the discoveries of factor locations.

It is generally recognized by students of maize inheritance that aleurone color is due to the interaction of five pairs of factors which have been called Aa, Cc, Rr, Prpr, and Ii. The determination of the C, R, Pr, and I factors was made by East and Hayes (7)[3] and East (6), although Emerson (8, 9, 10) presented important data which helped to substantiate the hypothesis. In a later paper, Emerson (11) presented facts which proved that there was another factor pair involved which was called Aa. A, C, and R are all necessary for the production of red aleurone color, and Pr, in the presence of A, C, and R, gives purple aleurone. When I is present this factor inhibits aleurone color. C and I are located in chromosome group I and are either very close together or are allelomorphic (Hutchison, 13). The factor R is at the left of the center of chromosome group II and A in the extreme left of chromosome group VII (Lindstrom, 15).

Emerson has produced appropriate aleurone testers which can be used to determine the aleurone color factors carried by any particular variety of corn. For example, the aleurone tester for A is genotypically aa, CC, RR. By crossing any variety of corn with the A tester, it is possible to find whether this variety carries the factor A or not. Similarly, aleurone testers known as C tester, R tester, and Pr tester are available.

Another fact regarding aleurone color is of interest and was brought out very clearly by Emerson in his paper in 1918 (11). Mottled seeds were observed originally by East and Hayes (7) and were found to be always heterozygous. Emerson proved that mottling was obtained from the genetic formula rrR, while a seed of either the formula RRR or RRr is self-colored.

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[2] Professor of Plant Breeding and Assistant Plant Breeder, respectively.

[3] Reference by number is to "Literature Cited," p. 766.

It has been pointed out by Emerson that other factors for endosperm color are involved but in many cases the differences are so small that classification is almost impossible. Fraser (12) called attention to intensified red and purple aleurone color in maize which was due to a factor pair which he called In in. When this factor is in the recessive condition in the presence of either red aleurone or purple aleurone, an intensified expression of the color is obtained. The factor In, in the presence of A, C, and R, produces light red aleurone, and in the presence of A, C, R, and Pr light purple aleurone color is obtained.

The purpose of this brief review of the previous status of the inheritance of aleurone color in maize is to furnish a background for an understanding of certain results which have been obtained recently in connection with genetic studies in maize at Minnesota.

PARENTAL MATERIAL USED AND CROSSES MADE

The results to be reported were obtained in connection with linkage studies of certain characters obtained from selfed lines of two Minnesota varieties, *viz.*, Rustler white dent and Minnesota No. 13 yellow dent. Crosses were made with the aleurone testers and a purple aleurone strain and the aleurone segregation studied in F_2. Some of the results obtained are summarized in Tables 1, 2, and 3. The strains of Rustler used for the crosses are unrelated, both having been selfed for several generations. The Rustler strain used for the cross reported in Table 1 and the Minnesota No. 13 strain, (Table 2), when crossed with the aleurone testers, were found to carry the aleurone factors A c r Pr, while the genotype of the other

TABLE 1.— *F_2 segregation, cross A tester (H1) x Rustler (H48).*

Ear No.	Purple	Red	Colorless
159-1	119	75	248
-3	121	80	255
-6	136	74	268
-7	107	68	251
-8	86	78	244
-4	90	58	199
-5	134	55	250
Total.......	793	488	1715
Total colored.....	1,281		

Rustler strain (Table 3), can only be assumed on the basis of the cross herein reported.

TABLE 2.— *F_2 segregation, cross A tester (409) x Minnesota No. 13 (H2-16).*

Ear No.	Purple	Red	Colorless
H46–1	103	60	192
–2	100	71	269
–3	135	68	271
–4	76	38	166
–5	85	55	216
Total...........	499	292	1114
Total colored ...	791		

TABLE 3.— *F_2 segregation, cross purple aleurone x Rustler white dent.*
Data furnished by Forrest Immer.

Ear No.	Purple	Red	Colorless
108	207	21	208
110	172	12	150
114	129	14	113
121	129	25	127
126	180	12	145
132	167	21	147
Total...........	984	105	890
Total colored....	1,089		

DISCUSSION OF RESULTS

It will be noted that in both of the crosses with the A tester (Tables 1 and 2) there are too many red seeds for a 3:1 ratio of purples to reds. Inasmuch as the A, C, and R factors are segregating a 27:37 ratio of colored to colorless would be expected in each of these crosses. The obtained results fit very well the expectation on this basis.

In the cross reported in Table 3 the red seeds appear much too few for a 3:1 ratio of purples to reds. Assuming two factors besides the Pr factor segregating for color, a 9:7 ratio of colored to colorless would be expected. The obtained segregation fits this expectation very well.

LINKAGE OF PR WITH EITHER C OR R

The results obtained in connection with these crosses can be explained by a linkage of the Pr factor with either C or R. On this basis, in the first two crosses (Tables 1 and 2), the factors would be linked in the repulsion phase, thus accounting for a greater proportion of red seeds than would be expected with independent segregation; while in the third cross (Table 3), the same factors would be linked in the coupling phase which would result in a lower proportion of reds than would be expected with independent segregation.

In another cross, segregating in a similar manner to the crosses reported in Tables 1 and 2, there was also segregation for shrunken seeds. Shrunken appeared to segregate independently of the Pr factor. The following results were obtained: Purple normal, 843; purple shrunken, 423; red normal, 525; and red shrunken, 243. Of the purple seeds 33.4% were shrunken, and of the red seeds 31.6% were shrunken. It appears that the Pr factor is segregating independently of the sh factor. Since C and sh are linked with only 3.5% crossing-over (Hutchison, 13), it follows that Pr and C are probably independent in inheritance. This would indicate that the Pr factor is linked with the R factor in linkage group II. Further work is in progress to bring more and better evidence on the linkage relations of the Pr factor. It is perhaps well to state that in the material here reported the separation of purple and red aleurone seeds was made very easily. This statement is made because in some cases, perhaps in the intense red and purple condition, it is rather difficult to separate accurately purple and red aleurone seed.

YELLOW ENDOSPERM COLOR IN MAIZE

East and Hayes (7) reviewed briefly the early work of Correns (4) and Lock (16) regarding the inheritance of endosperm color. In the report of East (5) and East and Hayes (7) it was pointed out that there were two yellow colors in the endosperm each behaving when crossed with its absence as an independent allelomorphic pair. The results were presented with the view that both of these yellow colors were of a similar nature and they were considered to result from duplicate genes. It was appreciated, however, that the color of the endosperm was very variable and East and Hayes stated that it was impossible always to classify pale yellow endosperm seeds correctly. This fact should have led the reader to appreciate that light yellow seeds were classified in these studies as yellow.

Kvakan (14), in 1924, presented an interesting study of the inheritance of brown aleurone color of maize which is dependent upon a factor which has been placed in chromosome group VIII. Kvakan points out that it is possible that this brown aleurone is the same thing as one of the yellow endosperm colors reported by East and Hayes and, if such is the case, concludes that the two yellow colors could not result from duplicate genes for endosperm color as has been supposed.

More recently Anderson (1) has presented a summary of some studies which he has made on yellow endosperm color of maize.

He finds that there are two yellow endosperm colors in maize, one a dark yellow color and the other a pale yellow. Unfortunately, none of the material which was studied by East and Hayes is now available so that it is impossible to determine the nature of their material.

The purpose of the present note is to present facts regarding yellow endosperm color which have been obtained recently. The facts indicate two rather unlike types of yellow endosperm color which are without doubt dependent upon different factors than the Yy factor pair for yellow endosperm color which is located somewhat at the left of the center of the V chromosome. These results were obtained from studies of crosses in which the Rustler glossy character was used. This glossy appears identical with the glossy which is called by Brunson (2) gl_1 and which is located in group VIII. Two rather clear cases of linkage relation with yellow endosperm color have been obtained and the appearance of the endosperm color has been determined. The material is not very extensive but the data obtained appear rather definite and similar results in each segregating population were obtained from all ears.

The pale yellow endosperm here referred to is a very pale or light yellow color. It seems similar to the pale yellow discussed by Anderson which he states never approaches orange or amber yellow and which, he also states, was observed by Dr. Demerec to be linked with a factor for pale seedling color. The data which indicated linkage are presented in Table 4. In this case the glossy character and white endosperm entered the cross from the same parent.

TABLE 4.—*F_2 population for interrelationship of pale yellow endosperm vs. white and glossy vs. normal.*

Greenhouse data, 1925.

Ear No.	Pale yellow endosperm		White endosperm	
	Normal plants	Glossy	Normal plants	Glossy
13b–1	256	33	43	76
–2	205	25	48	56
–3	307	53	37	64
–4	·315	33	55	102
–5	268	44	42	77
Total.........	1,351	188	225	375

The calculated coefficient of association by the method given by Collins (3) is 0.846 which corresponds to a gametic ratio of 3.87 :1 : 1 : 3.87, or a crossover percentage of 20.5.

The data for the deeper yellow color are given in Table 5.

The calculated coefficient of association is 0.361 which corresponds roughly to a gametic ratio of 1.6 : 1: 1 : 1.6, or a crossover percentage of 38.5

TABLE 5.—*F_2 population for interrelationship of yellow endosperm vs. white and Glgl.*

Ear No.	Yellow endosperm		White endosperm	
	Normal plants	Glossy	Normal plants	Glossy
A15a-1	158	43	55	32
-2	106	31	25	14
-3	169	41	48	27
-4	125	28	55	27
Total.........	558	143	183	100

Apparently the linkage relation between glossy and this yellow color is not as close as that of glossy and pale yellow endosperm, although as considerable variation is observed in studies of linkage relations in F_2 it is impossible to decide definitely without further investigations whether the factors for these two yellow colors are in the same or different location in the chromosome. Both of these factors are members of Group VIII and one of them gives a yellow endosperm color which, while perhaps slightly lighter than the ordinary yellow, could hardly be referred under the terminology of pale yellow. Plans are under way to study the interrelation of these two factors for yellow with the Yy factor pair which is located in Group V.

SUMMARY

Results are presented which indicate a linkage of the Pr factor with the R factor in linkage group II.

A brief discussion is given of studies of inheritance of yellow endosperm color and two different types besides the usual yellow color are discussed. One of these is somewhat darker than pale yellow and the other is a very pale yellow endosperm. The results given indicate that the factors which condition the development of these endosperm colors are located in chromosome VIII.

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THE FUNCTION OF ORGANIC MATTER IN THE SOIL[1]

Chas. E. Thorne[2]

The term "organic matter," as used with reference to the soil, is applied to materials of vegetable and animal origin which have become incorporated with the soil. Such materials, as well as the organisms from which they are derived, consist of three different groups of elementary substances: (1) Nitrogenous compounds, in which nitrogen is found in the comparatively inert form of organic nitrogen, or in that of ammonia when carried in fermenting manure; (2) the various mineral elements found in plant or animal; and (3) the carbonaceous matter—starch, sugar, fat, etc.—which goes to make up the complete structure of the living organism.

No fact has been more generally observed throughout the humid regions of the Temperate zones than that soils rich in organic matter are more productive than those in which such matter is relatively deficient. This observation has led to the advocacy of the plowing under of green crops and crop residues, and to the assumption that

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farm manure should be more effective than chemical fertilizers because of the fact that it carries carbonaceous substances in addition to its nitrogen and mineral elements.

It is undoubtedly true that bacterial and similar organisms in the soil play a very important part in converting both nitrogen and the mineral elements into forms available to higher plants, and that a supply of combined carbon is as necessary to the action of these organisms as it is to the growth of other vegetation. The carbon dioxide of the atmosphere, which is absorbed by their foliage, is believed to be a sufficient source of carbon for the growth of the higher plants, and Winogradsky has shown that the organisms through whose agency atmospheric nitrogen is converted into nitrate are able to utilize carbon dioxide. While it is believed that the organisms which are engaged in the pre-digestion of organic tissues derive their energy from the carbonaceous constituents of such tissues, it does not follow that these carbonaceous matters contribute directly to the growth of the higher plants. They may be merely vehicles in which nitrogen and the mineral elements are carried, and they may serve simply to supply the energy by which the nitrogen and mineral elements are liberated from their organic combinations, to be recombined with atmospheric oxygen into the nitrates and soluble oxides which the higher plants require for their nutrition.

The common idea that farm manure possesses fertilizing properties additional to those due to its nitrogen and mineral elements is accounted for in the fact that manure has usually been applied in such amounts as to carry much larger quantities of these elements than are given in chemical fertilizers. For example, many farmers will not consider the 15½ tons of manure used annually in the Rothamsted experiments a very extravagant dressing for an acre of land. But this quantity of manure is estimated to have carried as much nitrogen as is found in 1,250 pounds of nitrate of soda, as much phosphorus as is carried in 485 pounds of 16% acid phosphate, and as much potassium as is contained in 475 pounds of muriate of potash, or a total fertilizing content equivalent to 2,210 pounds of these chemicals which would cost about $62.00 an acre annually if purchased in these chemicals at present retail prices. Such an expenditure for the fertilizing of cereal crops would rightly be considered as wildly extravagant.

COMPOSITION OF MANURE

It is extremely difficult to fix upon an estimate of the average composition of farm manure, because it is so greatly affected by differences in feed, in the digestive processes of the animals producing it, in exposure, and in proportions of litter and of moisture in the samples taken for analysis.

The manure used at Rothamsted is estimated to have contained per 14 long tons or 31,360 pounds, 200 pounds of nitrogen, 78 pounds of phosphoric acid, and 236 pounds of potash, or the equivalent of 12.75 pounds of nitrogen, 2.19 pounds of phosphorus, and 12.44 pounds of potassium per ton of 2,000 pounds.[3]

The manure used in the Pennsylvania experiments is computed to have carried the equivalent of 9.8 pounds of nitrogen, 2.82 pounds of phosphorus, and 7.14 pounds of potassium per ton, and is classed as "yard manure."[4]

At the Ohio Experiment Station, Ames and his co-workers, in their studies connected with the experiments in the reinforcement of manure, found a range in the composition of a ton of fresh manure from fattening steers running from 10.30 to 17.48 pounds for nitrogen, from 1.68 to 3.23 pounds for phosphorus, and from 8.14 to14.36 pounds for potassium. They also found in the same original quantity of manure after three months' winter exposure in flat piles in an open barnyard a range from 7.18 to 9.48 pounds of nitrogen, 1.47 to 2.46 pounds of phosphorus, and 3.34 to 8.26 pounds of potassium. They further found that when fresh manure was dried for a week at a temperature of 140° F. it lost about 30% of its nitrogen.

Any one who has worked with manure has recognized the odor of escaping ammonia when manure is stirred. It seems probable that under the most careful treatment there will be some loss of nitrogen before the manure reaches the field, and that when the manure is spread as a top-dressing this loss may be very considerable. Usually, however, the temperature to which manure is exposed after spreading is much lower than that in the laboratory experiments referred to, while the ordinary rainfall will carry much of the escaping ammonia into the soil.

In any case, there will be a loss of the carbonaceous matter of the manure through the process of eremacausis, a fact familiar to every observer who has noted the gradual disappearance of manure or any other organic residue during long exposure to the weather.

In respect to the mineral constituents of manure there would seem to be no chance for loss except that of leaching, either in the stable or barnyard before it goes to the field, or in the field itself if the manure be left in piles for a considerable time before spreading. Ames and his co-workers found a loss in the stable of about 12% of the nitrogen and potassium as between manure collected on cement or on earth floors, these elements being carried chiefly in the urine, which will pass through the litter and be absorbed by the earth below unless litter be used in large quantity. This loss will be at the minimum in case of sheep fed under shelter, if manure and litter are allowed to accumulate for several months before removal.

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[3] HALL, A. D. The Book of the Rothamsted Experiments. London: J. Murray. 1905. (P. 34.)

[4] Penn. Agr. Exp. Sta. Bul. 175. 1920.

For these reasons the compositions given in Table 1 have been assumed as fair averages of the manures used in the experiments under review.

FIELD EXPERIMENTS IN THE USE OF MANURE

Farm manure has been used in comparison with chemical fertilizers on wheat and barley grown continuously at the Rothamsted Experiment Station since 1852; on corn, oats, and wheat grown in rotation with clover by the Pennsylvania Experiment Station since 1882; and on the same crops grown both continuously and in rotation with clover and timothy since 1894 and in several experiments over shorter periods by the Ohio Experiment Station. The average composition of the manures used in these experiments is estimated to have been approximately as shown in Table 1.

TABLE 1.—*Estimated average composition of farm manure in pounds per ton.*

Station	Manure treatment	Nitrogen	Phosphorus	Potassium
Rothamsted	——	12.7	2.2	12.4
Pennsylvania	Yard	9.8	2.8	7.1
Ohio	Stall	10.8	2.4	11.0
Ohio	Shed	9.0	2.3	9.0
Ohio	Yard	8.0	2.2	7.0
Ohio	Leached	7.5	2.0	7.0
Ohio	Sheep	25.0	4.7	20.0

In Table 1 the term "yard manure" is applied to the ordinary, mixed manure of the open barnyard which has received daily accretions during accumulation. "Stall manure" is in this case the manure from fattening steers, accumulated on cement floors, and moved directly from stable to field. "Shed manure" is the same manure accumulated on earth floors. "Leached manure" is the same manure after three months' exposure in the open barnyard. In the Ohio manures a deduction of 20% of the nitrogen has been made from the average analyses to cover losses in drying.

In the Rothamsted experiments 15½ short tons of manure per acre have been applied annually for 70 years to wheat and barley, grown continuously on the same land, with the outcome shown by 10-year periods in Table 2.

Table 2 shows that, with the exception of one decade, the wheat has given a larger yield from the smaller dosage in chemicals than from the larger one in manure. The yields of barley have been smaller from the chemicals than from the manure, apparently because of the smaller allowance of nitrogen given to the barley than to the wheat; but if the cost of the elements in manure is computed at the same rate as in chemicals, it will be found that the chemicals have been the most effective carriers. This is shown in Table 3 in which nitrogen is computed at 22½ cents a pound, equivalent to $70 a ton for nitrate of soda; phosphorus at 16 cents a pound, equivalent to $22.40 a ton for 16% acid phosphate; and potassium at 6 cents a pound, equivalent to about $50 a ton for muriate of potash. The results are shown for the average of the 70 years, 1852–1921.

TABLE 2.—*Fertilizing elements per annum and average annual yield by 10-year periods for wheat and barley grown continuously at Rothamsted.*

		Pounds per acre			Bushels per acre						
Plat No.	Treatment	N	P	K	1852 –61	1862 –71	1872 –81	1882 –91	1892 –01	1902 –11	1912 –21
					Wheat in Broadbalk Field						
2	Manure	200	34	195	34.2	37.5	28.7	38.2	39.2	34.7	27.0
8	Chemicals	129	28	83	36.1	40.5	31.2	38.4	38.5	37.2	27.4
7	Chemicals	86	28	83	34.7	35.9	26.9	35.0	31.8	31.0	23.2
6	Chemicals	43	28	83	27.2	25.7	19.1	24.5	23.1	21.4	16.6
					Barley in Hoos Field						
7–2	Manure	200	34	195	45.0	51.5	50.2	47.6	44.3	44.3	40.1
	Chemicals	43	28	83	46.1	46.4	41.0	40.7	36.3	38.4	36.3

Even if it is assumed that the estimate for nitrogen in the Rothamsted manure has been too high, because of probable loss between stable and field, it still remains true that the manured plats have received a far greater quantity of each of the fertilizing elements than those treated with chemicals.

TABLE 3.—*Cost of fertilizing elements per acre per annum and per bushel of increase for wheat and barley grown continuously at Rothamsted.*

Plat No.	Treatment	Cost of treatment per acre	Total yield in bushels	Increase from treatment in bushels	Cost of increase per bushel
			Wheat		
2	Manure	$62.14	34.3	22.2	$2.80
8	Chemicals	38.48	35.1	23.0	1.67
7	Chemicals	28.76	30.9	18.8	1.53
6	Chemicals	19.14	22.3	10.2	1.87
			Barley		
7–2	Manure	$62.14	46.0	32.0	$1.96
4 AA	Chemicals	19.14	39.2	25.2	.76

In Broadbalk Field the medium application of nitrogen has been the most efficient, considered from the standpoint of economy, thus suggesting that manure may have been used in such excessive quantity as to obscure its real value.

At the Ohio Experiment Station, corn, oats, and wheat have been grown continuously on the same land for 30 years. All the land has been dressed with ground limestone occassionally, four plats have received no other treatment, two plats have had barnyard manure every year at the rate of 2½ tons and 5 tons per acre, respectively, and four plats have received chemical fertilizers made up of nitrate of soda, acid phosphate, and muriate of potash.

The manure has been mixed, openyard manure from horses and cows such as would be found in most Ohio barnyards, and probably carried about 8 pounds of nitrogen, 2.2 pounds of phosphorus, and 7 pounds of potassium per ton. These estimates are based upon the fact that the manure has accumulated in the barnyard by daily accretions and has therefore suffered smaller loss from leaching than

TABLE 4.— *Annual treatment and yield per acre by 10-year periods of corn, oats, and wheat, each grown continuously at Ohio Experiment Station.*

Plat No.	Treatment	Fertilizing elements, pounds			Period and yield in bushels		
		Nitrogen	Phosphorus	Potassium	I	II	III
			Corn				
	None	—	—	—	21.51	9.42	9.10
5	Manure	20	5.5	17.5	32.82	21.34	17.78
6	Manure	40	11.0	35	41.62	32.42	27.51
3	Chemicals	25	4.2	12	38.97	27.41	26.73
9	Chemicals	50	8.4	24	46.44	41.85	34.29
2	Chemicals	25	11.2	41	45.91	37.45	33.30
8	Chemicals	50	11.2	41	48.49	45.18	38.00
			Oats				
	None	—	—	—	24.30	20.03	17.25
5	Manure	20	5.5	17.5	29.67	30.56	25.39
6	Manure	40	11.0	35	35.78	38.97	32.57
3	Chemicals	25	3.8	20.5	37.61	35.84	34.08
9	Chemicals	50	7.6	41	47.15	42.25	43.04
2	Chemicals	25	11.2	41	41.16	39.96	36.98
8	Chemicals	50	11.2	41	48.81	44.29	44.89
			Wheat				
	None	—	—	—	9.24	5.79	6.71
5	Manure	20	5.5	17.5	13.77	13.16	15.59
6	Manure	40	11.0	35	17.11	18.11	21.44
3	Chemicals	25	3.1	12	16.61	14.06	14.30
9	Chemicals	50	6.2	24	20.73	19.59	20.54
2	Chemicals	50	11.2	41	20.84	17.34	19.35
8	Chemicals	50	11.2	41	22.97	21.46	22.80

that upon which the investigations above reported were conducted, a part of it being comparatively fresh when applied. The yields obtained under these treatments are averaged by 10-year periods in Table 4.

Table 4 shows that no treatment has maintained the yield of corn or oats throughout the 30 years of this test, there being a steady decline in the yield of corn from decade to decade; and while the manured oats showed a larger yield during the second decade than during the first, the yield of this crop also was smaller under all treatments during the last decade than at the beginning.

The wheat under the 5-ton manure dressing shows a larger yield during the second period than during the first, and under all treatments a larger yield during the third period than during the second. That this gain was at least partly due to seasonal conditions is shown by the increase in the unfertilized yield during the last period.

In every case the largest yield has come from the chemical treatment on Plat 8, but this plat has received a larger total amount of the essential elements than any other.

TABLE 5.—*Total pounds of fertilizing elements and increase per acre and per pound of elements for corn, oats, and wheat, each grown continuously at the Ohio Experiment Station.*

Plat No.	Treatment	Total elements in pounds	Period and increase in bushels			Increase per pound of element in bushels		
			I	II	III	I	II	III
			Corn					
5	Manure	43.0	10.71	13.56	10.39	0.249	0.315	0.242
6	Manure	86.0	20.25	24.56	20.14	0.236	0.286	0.235
3	Chemicals	41.2	15.23	16.79	16.49	0.370	0.407	0.399
9	Chemicals	82.4	28.20	35.45	28.00	0.342	0.430	0.339
2	Chemicals	77.2	21.28	23.91	20.23	0.275	0.309	0.262
8	Chemicals	102.2	29.05	38.02	31.19	0.284	0.372	0.305
			Oats					
5	Manure	43.0	5.26	10.35	8.83	0.122	0.241	0.205
6	Manure	86.0	11.15	18.54	15.74	0.130	0.215	0.183
3	Chemicals	49.3	14.22	16.53	17.35	0.288	0.335	0.352
9	Chemicals	98.7	21.28	21.22	25.32	0.216	0.215	0.257
2	Chemicals	77.2	18.57	21.32	19.80	0.241	0.276	0.257
8	Chemicals	102.2	23.44	23.42	27.50	0.229	0.229	0.269
			Wheat					
5	Manure	43.0	4.20	6.86	8.18	0.098	0.160	0.190
6	Manure	86.0	7.50	11.95	14.02	0.087	0.139	0.163
3	Chemicals	40.1	7.19	7.93	7.11	0.179	0.198	0.177
9	Chemicals	80.3	11.79	14.12	14.58	0.147	0.175	0.181
2	Chemicals	77.2	11.52	11.51	12.36	0.149	0.149	0.160
8	Chemicals	102.2	13.67	15.70	16.10	0.134	0.153	0.157

Table 5 shows the total dressing of each plat in pounds of essential elements, the increase in bushels per acre for each treatment, and the increase per pound of element in fertilizers or manure.

In planning this experiment, in 1893, the intention was to apply the different elements to Plats 3 and 9 in approximately the same ratio in which they are found in the plant, but the more perfect knowledge of the composition of the plant, on the one hand, and of the relative availability of the different elements, on the other, which has been obtained by experience since that time has made it evdent that phosphorus is given in too small a proportion, especially to the wheat, relative to the other elements. Table 5 shows, however, that in every case, except the smaller manure dressing on wheat, the increase per unit of fertilizing element in chemicals has been equal to or greater than that from the corresponding manure treatment.

EXPERIMENTS WITH ROTATED CROPS

At the Pennsylvania Experiment Station corn, oats, wheat, and clover have been grown in rotation since 1882, each crop being grown every year. In this test on Plats 16, 18, and 20 farm manure has been used on every corn and wheat crop at rates of 6, 8, and 10 tons per acre, respectively, equivalent to annual dressings of 3, 4, and 5 tons. A chemical fertilizer, made up of nitrate of soda, superphosphate composed of dissolved boneblack until 1915 and of acid phosphate since, and muriate of potash, has been used on the same crops on plats 26, 27, and 28 in quantities carrying the annual equivalents of nitrogen, phosphorus, and potassium shown in Table 6. This table also gives the average yields for the 25 years, 1882–1906, and the 15 years, 1907–21, as computed from the annual report of that station for 1907–08 and from Bulletin 175. In these publications the content of manure is computed at 9.8 pounds of nitrogen, and the equivalents of 2.8 pounds of phosphorus and 7.14 pounds of potassium per ton.

The Ohio Experiment Station has in progress two duplicate experiments in which fertilizers and manure are being used on the same rotations, one pair being located in the northern part and the other in the southern part of the state. A five-year rotation of corn, oats, wheat, clover, and timothy, was begun at Wooster in 1894 and at Strongsville a year later. In 1900 each of these tests was divided by liming half the land, the other half being left unlimed at Wooster and treated with raw phosphate rock (floats) at Strongsville. The cropping system was changed at Strongsville in 1915 by substituting soybeans, to be mown for hay, for the timothy, and changing the order of cropping to corn, oats, soybeans, wheat, and clover. In 1905

TABLE 6.—*Total yield, cost of treatment, and total and net values of crops grown in rotation at the Pennsylvania Experiment Station.* All computations per acre per annum

Plat No.	Treatment	Fertilizing elements in pounds Nitrogen	Phosphorus	Potassium	Cost of treatment	Crop yields Corn in bushels	Oats in bushels	Wheat in bushels	Hay in pounds	Value of crops Total	Net
					25 years, 1882–1906						
16	Manure	29	8	21	$ 9.06	57.50	39.40	22.70	3,875	$30.82	$21.76
18	Manure	39	11	28	12.22	53.50	41.40	23.50	4,156	31.01	18.79
20	Manure	49	14	35	15.37	57.10	41.40	23.90	4,119	31.30	15.93
26	Chemicals	12	10.5	41	6.84	56.90	40.70	22.90	4,232	31.56	24.72
27	Chemicals	24	10.5	41	9.54	56.70	41.90	24.20	4,300	32.20	22.66
28	Chemicals	36	10.5	41	12.24	57.00	41.70	25.00	4,266	32.42	20.18
					15 years, 1907–1921						
16	Manure	29	8	21	$ 9.06	54.30	46.10	25.63	3,686	$31.54	$22.48
18	Manure	39	11	28	12.22	56.43	45.57	26.17	4,052	32.76	20.54
20	Manure	49	14	35	15.37	60.03	49.40	29.23	4,403	35.57	20.20
26	Chemicals	12	10.5	41	6.84	57.43	48.43	23.70	3,941	32.33	25.49
27	Chemicals	24	10.5	41	9.54	59.63	48.83	25.80	3,735	33.09	23.55
28	Chemicals	36	10.5	41	12.24	60.47	47.57	27.40	3,903	33.92	21.68

two three-year rotations of corn, wheat, and clover were begun, one in southeastern Ohio at Carpenter, Meigs County, and one in southwestern Ohio at Germantown, Montgomery County, the treatment of Plats 1 to 20 being the same in the two tests.

If 20% of the nitrogen in the manure is deducted to offset losses in drying, the net values for the manured crops for Plats 16, 18, and 20 would be $23.06, $20.55, and $18.14, respectively, for the first period, and $23.78, $22.29, and $22.41 for the second period.

In the Wooster and Strongsville tests mixed yard manure has been used, and its composition is computed at 8 pounds of nitrogen, 2.2 pounds of phosphorus, and 7 pounds of potassium per ton. The manure has been applied at the rate of 8 tons per acre each to corn and wheat on Plat 18 and in half that quantity on Plat 20. The chemicals have consisted of nitrate of soda, acid phosphate, and muriate of potash, and have been divided among the three grain crops, except on Plat 14 on which the treatment has been divided between the corn and wheat.

In the Carpenter test the manure has contained some sheep manure during recent years. At Germantown it has been produced over most of the period by fattening steers fed on cemented floors. In both these tests it has been used at the rate of 5 tons per acre, all on corn, and has been followed by 1,000 pounds of limestone on wheat in the treatments here reported On Plat 29, at Germantown, the manure is reinforced with phosphate—raw phosphate the first 12 years and acid phosphate since.

No chemical application in these tests is exactly comparable in composition with manure. At Wooster and Strongsville the treatment on Plat 12, which consists of 720 pounds of nitrate of soda, 320 pounds of 14% acid phosphate, and 260 pounds of muriate of potash for each five-year period, is the nearest approach to the treatment of Plat 18, which receives 16 tons of barnyard manure during the same period; while Plat 14, receiving 320 pounds of nitrate of soda, 240 pounds of acid phosphate, and 180 pounds of muriate of potash is more nearly comparable with Plat 20, which receives 8 tons of manure. These two plats make the better comparison because both the manure and the fertilizers are divided between the corn and the wheat, whereas the oats receives part of the fertilizer on Plat 12 but no direct manuring on Plat 18.

The treatment on Plat 12 has been less efficient in respect to effect per pound of elements contained than the treatment on Plat 11 in which the nitrogen is reduced and on Plat 17 in which there is a further reduction of nitrogen together with an increase of phosphorus.

At Germantown and Carpenter Plats 14 and 15 receive the same total quantities of the fertilizing chemicals; but on Plat 14 they are divided between the corn and wheat, while on Plat 15 they are all given to the corn, the wheat receiving 1,000 pounds of limestone.

The results at Wooster are computed separately for the limed and unlimed land for the average of the 20 years, 1904–1923; those at Strongsville are for the combined average of the limed and floats-treated land for the 31 years, 1895–1925; and those at Germantown and Carpenter are for the 22 years, 1904–1925.

The effect of the different treatments, as shown in the total produce, is given in Table 7, which also gives the number of pounds of nitrogen, phosphorus, and potassium applied per acre per annum in

TABLE 7.—*Fertilizing elements and increase of total produce per acre per annum and increase per pound of fertilizing elements for crops grown in rotation by Ohio Experiment Station.*

Plat No.	Treatment	Fertilizing elements in pounds per acre per annum Nitrogen	Phosphorus	Potassium	Total
		Wooster and Strongsville			
18	Manure	29.0	7.0	22.0	58.0
12	Chemicals	23.0	4.0	22.0	49.0
20	Manure	14.5	3.5	11.0	29.0
14	Chemicals	10.0	3.0	15.0	28.0
11	Chemicals	15.0	4.0	22.0	41.0
17	Chemicals	7.5	6.0	22.0	35.5
		Carpenter and Germantown			
17	Manure[b]	15.8	3.9	18.6	38.3
29	Manure[ab]	15.8	8.9	18.6	43.3
15	Chemicals[b]	16.5	10.4	11.1	38.0
14	Chemicals	16.5	10.4	11.1	38.0

Increase of total produce in pounds

		Unlimed land Wooster		Limed land Wooster		Strongsville	
		Per acre	Per pound of element	Per acre	Per pound of element	Per acre	Per pound of element
18	Manure	2,427	41.9	2,414	41.6	1,198	18.6
12	Chemicals	2,014	41.1	1,986	40.5	1,432	24.7
20	Manure	1,333	46.0	1,338	46.1	770	24.2
14	Chemicals	1,409	50.3	1,315	47.0	934	29.3
11	Chemicals	1,980	48.3	1,920	46.8	1,086	26.5
17	Chemicals	1,892	53.3	2,099	59.1	1,115	31.4
		Carpenter[b]		Germantown[b]			
17	Manure[b]	1,519	39.7	1,354	35.4		
29	Manure[ab]	——	——	1,651	38.1		
15	Chemicals[b]	1,975	52.0	1,958	51.5		
14	Chemicals	1,883	41.6	2,003	52.7		

[a] Phosphated manure, Germantown only.

[b] These plats receive limestone also.

each treatment, the annual increase per acre, and the increase per pound of total elements in the fertilizer.

Table 7 illustrates the law of diminishing returns in each carrier. The larger dressing of manure produces the larger total increase, but the smaller increase per pound of fertilizing elements, and the same is true of the chemicals. In every case the lowest effectiveness of the chemicals per unit is greater than the highest of the manure, excepting only the larger dressing of chemicals on Plat 12 at Wooster. This plat receives the same quantities of phosphorus and potassium as Plat 11, but 50% more nitrogen; while Plat 17, with the same quantity of potassium, receives only half as much nitrogen as Plat 11 or one-third as much as Plat 12, but it gets 50% more phosphorus than either Plat 11 or Plat 12. On Plat 17 the effectiveness per pound of total elements carried is greater than on any other plat in the series.

This outcome raises the suspicion that the relatively inferior effect of manure and of the chemical dressing on Plat 12 may be due to a lack of sufficient phosphorus to balance the nitrogen carried. This point is further suggested in the Carpenter and Germantown results. Here the treatment of Plats 14 and 15 carries more nitrogen and less potassium than that carried in the manure; but the proportion of phosphorus to the other elements is much greater in the chemicals than in the manure, except on Plat 29, where the difference is not so great.

Because of these results, in the spring of 1921 the dose of phosphorus on Plat 12 at Wooster and Strongsville was increased to three times its former quantity, the nitrogen and potassium being left unchanged. The grain crops have completed one entire rotation since this change was made, and while this period is too short to justify final conclusions, the results thus far have been as shown in Table 8, in which the increase at Wooster is computed for the average of the limed and unlimed land.

TABLE 8.—*Increase of total produce since reinforcement of treatment on Plat 12 at Wooster and Strongsville.*

Plat No.	Fertilizing elements in pounds per acre per annum				Increase of total produce in pounds			
					Wooster		Strongsville	
	Nitrogen	Phosphorus	Potassium	Total	Per acre	Per pound of element	Per acre	Per pound of element
18	29	7	22	58	2,469	42.6	1,318	22.7
12	23	12	22	57	2,468	43.3	1,970	34.5

In the Carpenter and Germantown tests the manuring or fertilizing is alternated with liming, except on Plat 14, and the effect of this

TABLE 9.—*Increase in total produce per annum wit reinforcement of nure.*

Treatment	Duration of test in years	Plat No.	Elements i atment in pound er ac er annum				Increase in pounds	
			Nitrogen	Pl iorus	Potassium	Total	Per acre	Per pound of elements
	Wooster: 3-year rotation (manur							
Yard manure, untreated	28	15	20.0	5.3	13.3	38.6	1,562	40.4
Yard manure, phosphated	28	5	20.0	1.9	13.3	45.2	2,569	56.8
Stall manure, untreated	28	16	25.3	6.4	29.0	60.7	1,888	31.1
Stall manure, phosphated	28	6	25.3	3.0	29.0	67.3	2,901	43.1
	Wooster: 4-year rotation (supplemental anure test)							
Shed manure, untreated	11	29	9.0	2.3	9.0	20.3	497	24.5
Shed manure, phosphated	11	30	9.0	0.2	9.0	28.2	906	32.1
Chemicals	11	26	9.5	2.0	6.0	17.5	478	27.9
Chemicals	11	27	9.5	10.4	6.0	25.9	1,059	40.9
	Germantown: 3-year cere l rotation (manure test)							
Yard manure, untreated	10	23	12.5	3.3	8.3	24.1	708	29.3
Yard manure, phosphated	10	26	12.5	7.7	8.3	28.5	1,194	41.9
Stall manure, untreated	10	24	15.0	4.0	16.6	35.6	1,275	35.8
Stall manure, phosphated	10	27	15.0	8.4	16.6	40.0	1,929	48.2
	Hamilton County experiment farm: I— Cereal rotation, II—Potato rotation.							
I—Shed manure, untreated	13	8	22.5	5.7	22.5	50.7	1,116	22.0
I—Shed manure, phosphated	13	9	22.5	12.7	22.5	57.7	1,208	20.9
II—Shed manure, untreated	12	9	48.0	12.3	48.0	108.3	1,679	15.5
II—Shed manure, phosphated	12	9	48.0	21.6	48.0	117.6	2,116	18.0
	Clermont County experim nt farm: Potato rotation							
Stall manure, untreated	12	8	48.0	12.3	48.0	108.3	2,042	18.8
Stall manure, phosphated	12	9	48.0	21.6	48.0	117.6	2,350	20.0
	Washington Cou y experiment arm							
Sheep manure, untreated	10	12	20.0	4.7	20.0	44.7	927	20.7
Sheep manure and phosphate	10	13	20.0	3.4	20.0	53.4	1,234	23.1
Sheep manure and phosphate	10	15	20.0	8.7	20.0	58.7	1,264	21.5

liming is credited to the manure or fertilizer. The Carpenter soil is derived from sandstone and that at Germantown from limestone gravel; hence the limed land shows the greater effect from treatment at Carpenter, while the effect of the treatment on Plat 14 is greater at Germantown.

THE REINFORCEMENT OF MANURE

Additional light is thrown on the point under discussion by the experiments in the reinforcement of manure which are being conducted by the Ohio Experiment Station. The results of these experiments are shown in Table 9. The first of these tests was begun on the original station farm at Wooster in 1897; the second, on the Germantown farm, in 1904: and others on the annex to the Wooster farm, and on several of the county farms, 1912 to 1915.

In two of these tests two kinds of manure are used, one which has been taken direct from the stable to the field without exposure to the weather, and one which has been exposed for about three months during the winter in flat piles in an open barnyard, the same original quantity of manure being used in each test. In all the tests the reinforcement has consisted in adding acid phosphate to the manure, the phosphate being used in the arbitrary quantity of 40 pounds per ton of manure in most of the tests, while in others it has been used in larger quantities and the attempt has been made to make up chemical fertilizers having approximately the same quantities of the essential elements as are found in manure.

TABLE 10.—*Unfertilized yields and increases from treatment in bad seasons in bushels per acre.*

Crop and treatment	Plat No.	Unlimed		Limed	
		1910	1924	1910	1924
Corn					
Unfertilized yield..........		5.61	1.02	7.79	10.92
Increase from manure.......	18	32.23	19.51	29.43	34.19
Increase from chemicals.....	12	5.10	22.29	10.38	50.04
Increase from manure.......	20	10.36	6.00	18.07	16.74
Increase from chemicals.....	14	5.10	11.39	7.67	25.26
Wheat					
		1912	1920	1912	1920
Unfertilized yield...........		0.74	2.11	1.35	7.72
Increase from manure.......	18	7.39	18.11	12.14	19.36
Increase from chemicals.....	12	5.61	16.75	11.01	13.08
Increase from manure.......	20	3.94	9.28	6.39	13.31
Increase from chemicals.....	14	7.55	13.36	8.45	14.00

Table 9 shows that on all these widely scattered soils, except in Hamilton County, the reinforcement of manure with phosphorus has materially increased its effectiveness, although the effect of the reinforced manure still falls slightly below that of the most effective chemical dressing, as shown in Table 7.

In the cereal rotation in Hamilton County the total yield is increased by phosphating the manure, but the increase per unit is diminished. In the potato rotation, however, the results are consistent with all the rest in showing not only an increased yield but an increase per unit of fertilizing elements.

RELATIVE EFFECT OF MANURE AND CHEMICALS IN BAD SEASONS

There have been two seasons each for corn and wheat when the yields fell much below the general average, 1910 and 1924 for corn, and 1912 and 1920 for wheat. The relative effect of manure and chemicals in these seasons is shown in Table 10.

These results are contradictory, the increase in corn from both manure dressings being greater in 1910 and smaller in 1924 than that from the chemicals and that in wheat being greater on Plat 18 than on Plat 12 and smaller on Plat 20 than on Plat 14 in both seasons.

In 1910 the corn suffered from a cold spring followed by a severe drouth beginning in June and lasting until near the end of September. In 1924 cold, wet weather throughout the spring and early summer delayed the planting and growth.

In 1912 the wheat suffered from excessive rains during April and May, followed by cold, reaching the freezing point on June 8. January, 1920, was one of the coldest months recorded in Ohio, and was followed by a sheet of ice several inches thick lasting through February and making plant growth practically impossible. The cold continued through the spring, with excessive rainfall in April.

RESIDUAL EFFECT OF MANURE AND CHEMICALS

It is claimed that, while manure may not produce any greater immediate yield than chemicals, its effect is more permanent. Table 2 shows that in Broadbalk Field Plats 2 and 8 have run neck to neck for 70 years, with Plat 8 slightly ahead.

During the progress of the Ohio experiments it has been observed that the hay crops seemed to show a larger response to manure than to chemicals. One reason for this was evident in the field, namely, that the clover on the manured land showed a larger admixture of timothy than on the land receiving chemicals. Apparently, the manure had carried sufficient timothy seed materially to thicken the

TABLE 11.—*Average unfertilized yields, increase due to treatment, and percentage of increase to unfertilized yield in Ohio experiments.*

Crop and treatment	Plat No.	Grain in bushels	Straw in pounds	Total produce in pounds	Percentage increase	Grain in bushels	Straw in pounds	Total produce in pounds	Percentage increase
		Five-year rotations							
		Wooster, 32 years				Strongsville, 31 years			
Corn									
Unfertilized yield	—	26.48	1,477	3,330	—	27.87	1,775	3,726	—
Increase from manure	18	27.74	848	2,790	83.8	15.16	593	1,654	44.4
Increase from chemicals	12	22.75	726	2,318	69.9	13.80	600	1,566	41.8
Increase from manure	20	15.77	487	1,577	47.3	9.56	357	1,026	27.6
Increase from chemicals	14	17.74	556	1,798	54.0	9.04	379	1,012	27.2
Oats									
Unfertilized yield	—	31.39	1,297	2,301	—	36.94	1,382	2,564	—
Increase from manure	18	13.51	811	1,245	54.1	8.12	394	654	25.5
Increase from chemicals	12	19.91	1,073	1,710	63.3	16.17	550	1,067	41.6
Increase from manure	20	7.41	399	663	24.5	5.14	289	453	17.7
Increase from chemicals	14	9.46	439	742	27.4	4.66	171	320	12.5
Wheat									
Unfertilized yield	—	11.32	1,138	1,817	—	11.66	1,015	1,714	—
Increase from manure	18	14.28	1,619	2,476	136.3	8.50	916	1,426	83.2
Increase from chemicals	12	17.87	2,026	3,099	170.5	14.24	1,404	2,258	131.7
Increase from manure	20	9.35	978	1,539	84.7	5.36	555	877	51.2
Increase from chemicals	14	15.22	1,627	2,540	139.8	11.23	1,057	1,731	101.0
Clover									
Unfertilized yield	—	—	—	1,537	—	—	—	2,010	—
Increase from manure	18	—	—	2,156	140.3	—	—	1,058	52.6
Increase from chemicals	12	—	—	1,512	98.3	—	—	837	41.6

Increase from manure.......	20	——	——	1,132	73.6	——	——	724	36.0
Increase from chemicals.....	14	——	——	916	59.6	——	——	675	33.6
Timothy									
Unfertilized yield...........	—	——	——	2,435	——	——	——	2,380	——
Increase from manure.......	18	——	——	1,786	73.3	——	——	712	29.9
Increase from chemicals.....	12	——	——	931	38.2	——	——	315	13.2
Increase from manure.......	20	——	——	1,005	41.3	——	——	441	18.5
Increase from chemicals.....	14	——	——	563	23.1	——	——	362	15.2
		Three-year rotations							
		Carpenter, 22 years				Germantown, 22 years			
Corn									
Unfertilized yield...........	—	24.06	1,340	3,024	——	39.81	2,051	4,838	——
Increase from manure.......	17	17.96	597	1,854	61.3	19.00	991	2,321	47.9
Increase from manure.......	29	——	——	——	——	19.15	1,188	2,528	52.2
Increase from chemicals.....	15	22.18	798	2,350	77.8	20.88	1,204	2,665	55.1
Wheat									
Unfertilized yield...........	—	8.41	815	1,320	——	10.36	1,294	1,915	——
Increase from manure.......	17	10.19	1,012	1,623	122.9	5.47	741	1,069	55.8
Increase from manure.......	29	——	——	——	——	8.87	1,088	1,620	85.4
Increase from chemicals.....	15	12.51	1,274	2,024	153.3	12.03	1,373	2,095	109.2
Clover									
Unfertilized yield...........	—	——	——	1,050	——	——	——	2,044	——
Increase from manure.......	17	——	——	1,079	102.8	——	——	673	32.9
Increase from manure.......	29	——	——	——	——	——	——	804	39.3
Increase from chemicals.....	15	——	——	1,550	147.6	——	——	1,113	54.4

TABLE 12.—*Total fertilizing elements given per acre during one rotation, amount recovered in increase of grain crops, and balance left for hay crops.*

Station and treatment	Plat No.	Applied in treatment in pounds			Recovered in increase in pounds			Balance in pounds		
		Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
Wooster										
Manure	18	128	35	112	73	11.0	39	55	24.0	73
Chemicals	12	114	20	108	79	11.3	46	35	8.7	62
Manure	20	64	17.5	56	41	6.5	23	23	11.0	33
Chemicals	14	50	15	75	57	8.9	31	—7	6.1	44
Strongsville										
Manure	18	128	35	112	43	6.3	23	85	28.7	89
Chemicals	12	114	20	108	56	9.0	31	58	11.0	77
Manure	20	64	17.5	56	27	3.9	14	37	13.6	42
Chemicals	14	50	15	75	35	5.5	18	15	9.5	57
Carpenter										
Manure	17	45	11.5	45	40	5.9	19	5	5.6	26
Chemicals	15	50	31.5	33	50	7.2	24	0	24.3	9
Germantown										
Manure	17	45	11.5	45	37	5.1	19	8	6.4	26
Manure	29	45	25.0	45	45	6.2	24	0	18.8	21
Chemicals	15	50	31.5	33	52	7.4	28	—2	24.1	5

stand of that crop. In Table 11 are shown for each crop the average unfertilized yield and the increases due to the different treatments, all computed per acre per annum, and the percentage which each increase constitutes of the unfertilized yield for the entire term of the different experiments.

Table 11 shows that in the comparison between Plats 18 and 12 in both the longer rotations manure has produced the greater increase at Wooster in corn, clover, and timothy, while oats and wheat have shown a greater effect from chemicals. As between Plats 20 and 14, which is really the fairer comparison, the chemicals have shown the greater effect at Strongsville on all the grain crops except oats, the manure remaining ahead on the hay crops.

In the shorter rotations, however, the increase from the chemicals has been decidedly greater than that from the manure in every comparison. This outcome would seem to be fully explained by Table 12, which gives the total quantity per acre of each of the fertilizing elements given to each of the plats under consideration during one rotation, the amount recovered in the increase of the grain crops, and the balance left for the hay crops.

Table 12 shows that in every case a larger quantity of each of the three elements has been recovered in the grain crops treated with chemicals than in those treated with manure; that in the longer rotations at Wooster and Strongsville the manure has carried a larger quantity of each element, excepting potassium on Plat 14, than the chemicals; and that there has been a much larger residue left over for the hay crops from the manure than from the chemicals.

At Carpenter and Germantown the manure dressing has contained a smaller quantity of each element, except potassium, than the chemicals, even when reinforced with phosphorus, also, there has been relatively a more complete utilization by the grain crops of all the elements, both in manure and chemicals, and consequently a smaller amount has been left over for the clover.

That it takes manure longer to get into action than chemicals is shown by Table 13, which gives the total produce of the annual increase from the different treatments by 10-year periods for Wooster and Strongsville and by 6-year periods for Germantown and Carpenter.

Table 13 shows that during the first period the effect of the chemicals was in every case greater than that of the manure, that during the second period the large dressing of manure passed the chemical dressing on Plat 12 at Wooster by a small margin, and that during the third period this margin became larger and Plat 20 caught up with

TABLE 13.—*Annual increase of total produce by periods in pounds per acre.*

Station and treatment	Plat No.	Total elements	Period and increase		
			I	II	III
Wooster					
Manure	18	58	1,241	2,106	2,415
Chemicals	12	49	1,504	2,020	1,985
Manure	20	29	824	1,386	1,318
Chemicals	14	28	1,159	1,427	1,309
Strongsville					
Manure	18	58	991	1,274	1,300
Chemicals	12	49	1,187	1,328	1,785
Manure	20	29	624	762	875
Chemicals	14	28	929	864	999
Germantown					
Manure	17	38	1,280	1,215	1,614
Chemicals	15	38	1,749	1,969	2,296
Carpenter					
Manure	17	38	712	1,413	1,814
Chemicals	15	38	1,222	2,100	2,322
	Average unfertilized yields				
Wooster			2,061	2,495	2,221
Strongsville			1,944	2,729	2,793
Germantown			3,390	2,870	2,850
Carpenter			2,811	1,820	1,326

Plat 14 In the other three tests the increase from the chemical dressings has been larger than that from the manures in every comparison, although there has been a gain in the effectiveness of both chemicals and manure

In this table the limed and unlimed increases at Wooster are combined, and the timothy and soybeans are omitted from the Strongsville comparison because of the irregular yields during the middle period.

The smaller increases shown for Strongsville than for Wooster are in part due to the phosphate treatment, which has been applied to all the land and thus has increased the yield of the check plats and by partly satisfying the demand for phosphorus has reduced the apparent effect of that element in the fertilizer.

The contradictory behavior of Plat 12 at Wooster and Strongsville during the third period has been due in part to the change of treatment on this plat. The Wooster results are computed to 1923, whereas those for Strongsville are computed to 1925, thus giving two additional seasons for this change to show its effect at Strongsville.

MISSOURI EXPERIMENTS

Bulletin 182 of the Missouri Experiment Station reports the results of a series of experiments in continuous and rotative cropping with manure and chemical fertilizers that had been conducted at that station during the 30 years, 1889–1918. In these experiments manure—much of which had been drawn from livery stables—had been used at the rate of 6 tons per acre annually on every crop, and chemical fertilizers, made up of nitrate of soda, acid phosphate and muriate of potash and calculated to carry per acre and for the different crops the same quantities of nitrogen, phosphorus, and potassium found in 80 bushels of corn with its stover, 60 bushels of oats with its straw, 40 bushels of wheat with its straw, and 3 tons each of clover and timothy hay, were used in comparison with the manure.

It was probably assumed in planning this experiment that 6 tons of horse manure would carry approximately the same quantities of nitrogen, phosphorus, and potassium as would be found in the average dressing of the chemicals above named, an assumption that would be justified if manure could be taken fresh from stable to field without loss.

The outcome of this test, as averaged in the bulletin referred to, for the 30 years, 1889–1918, for the continuously grown wheat and a six-year rotation, are shown in Table 14.

TABLE 14.—*Thirty-years average annual yield and increase per acre of crops grown continuously and in six-year rotation at the Missouri Experiment Station.*

Cropping system and crop	Treatment	Yield Untreated	Yield Treated	Increase
Continuous				
Wheat, bushels	Manure	9.5	18.1	8.6
	Chemicals	9.5	18.7	9.2
Rotative				
Wheat, bushels	Manure	20.1	26.5	6.4
	Chemicals	20.1	30.0	9.9
Corn, bushels	Manure	41.5	44.0	2.5
	Chemicals	41.5	41.6	0.1
Oats, bushels	Manure	27.2	25.7	—1.5[a]
	Chemicals	27.2	39.1	11.9
Clover hay, lbs.	Manure	2,173	3,981	1,808
	Chemicals	2,173	3,636	1,463
Tim'thy hay, lbs.	Manure	2,446	4,335	1,889
	Chemicals	2,446	3,810	1,364

[a] The low yield of manured oats is ascribed to lodging.

This test agrees with the five-year rotation at Wooster in showing the larger increase from chemicals on wheat and oats and from manure on the hay crops. A study of the Missouri test by periods shows a decreasing rate of yield in the corn and hay crops, the corn yields being 45.9, 49.7, and 33.0 bushels per acre in successive 10-year periods, while clover was harvested in only 5 of the 10 seasons during the second period and in only 4 during the third. The Missouri soil is described as closely allied to the Putnam silt loam, a type which is found elsewhere to be deficient in lime, and there would seem to be no doubt that the soil on which these experiments are located is going through the same process of lime depletion that has been experienced on the Wooster soil. The earlier date at which cultivation was begun on the Wooster soil would explain the earlier appearance of lime-hunger there. On such a soil manure should produce a relatively larger increase than the chemicals used in these tests because of the lime it contains.

The increases in the Missouri test, however, have been small as compared with the elements of fertility supplied. Considering the nitrogen alone, the quantities supplied in nitrate of soda and recovered in increase of crop in the four rotations named, excluding the timothy crops, have been approximately as shown in Table 15, in which only the largest applications of nitrate used for the Ohio and Pennsylvania tests are included.

TABLE 15.—*Nitrogen balance sheet in cereal rotations in pounds per acre.*

Crop	Columbia, 30 years		Pennsylvania, 40 years		Wooster, 30 years[a]		Strongsville, 30 years	
	Given	Recovered	Given	Recovered	Given	Recovered	Given	Recovered
Corn	118	0	72	26	38	22	38	13
Oats	58	10	0	13	38	19	38	14
Wheat	75	17	72	24	38	30	38	24
Clover	120	31	0	45	0	28	0	16

[a] Unlimed land.

Table 15 shows that nitrogen has been given in the Missouri test, both in manure and chemicals, far beyond the ability of the crops to utilize it, a point to which the authors of the Missouri bulletin call attention, and an analysis of the soil, made after the experiment had been running for 25 years, indicates that the larger part of this surplus nitrogen has disappeared. The manured land shows a larger increase of nitrogen than that receiving chemicals, but this would seem to be fully accounted for in the less soluble condition of the manure nitrogen.

Until a better account can be rendered for the nitrogen and mineral constituents of manure than is shown in this outcome there would seem to be no room to credit its organic matter with any other function than to carry these constituents.

It is difficult to account for the low response of corn to both manure and chemicals, but the difference is probably due to the lime rather than to the carbonaceous matter in the manure.

INDIANA EXPERIMENTS

Comparisons of the effect of manures and chemical fertilizers were begun at the Indiana Experiment Station in 1890. The results of some of these experiments are summarized in Tables 16 and 17, compiled from Bulletins 198 and 222, and from unpublished data kindly supplied by Professor Wiancko. Because of changes in treatment in 1917 these tables cover only the 27 years, 1890–1916. In Table 16 the factors given for stall manure in Table 1 are used for computing the composition of the manure used on the continuously grown crops and the four-year rotation. The composition of that used in the five-year rotation is computed in Table 17 from analyses of fresh horse and cattle manures made at the Ohio station, which have shown the following average composition in pounds per ton of manure:

	Nitrogen	Phosphorus	Potassium
Horse manure	13.9	2.2	12.7
Cattle manure	12.0	2.7	9.2

Of course, it is no more probable in this case than in those previously considered that the manures reached the field without any loss, but the tables show that a considerable reduction in the assumed

TABLE 16.— *Crops grown continuously and in four-year rotation at Indiana Experiment Station, 27 years' average application of fertilizing elements and increase of total produce, all per acre per annum.*

Treatment	Fertilizing elements in pounds				Increase in pounds	
	Nitrogen	Phosphorus	Potassium	Total	Per acre	Per pound of element
		Continuous corn				
Manure, 6.5 tons....	70.2	15.6	71.5	157.3	1.732	11.0
Manure, 3.6 tons....	38.9	8.6	39.6	87.1	1,581	18.1
Chemicals.........	82.8	13.3	42.3	138.4	1,287	9.3
Chemicals.........	34.3	7.3	16.2	57.8	1,090	18.9
		Continuous wheat				
Manure, 4.2 tons. ..	45.3	10.1	46.2	101.6	1,348	13.3
Manure, 2.5 tons....	27.0	6.0	27.5	60.5	874	14.4
Chemicals.........	27.5	7.3	21.7	56.5	858	15.2
Chemicals.........	15.7	3.8	10.6	30.1	569	18.9
		Four-year rotation of corn, oats, wheat, and clover				
Manure, 3.55 tons...	38.3	8.5	39.0	85.8	997	11.6
Manure, 2.12 tons...	22.9	5.1	23.3	51.3	896	17.5
Chemicals.........	38.6	7.4	22.3	68.3	1,032	15.0
Chemicals.........	16.5	3.6	9.8	29.9	694	23.2

TABLE 17.—*Crops grown in five-year rotation at Indiana Experiment Station, 27 years' average application of fertilizing elements and increase in total produce, all per acre per annum.*

Treatment	Fertilzing elements in pounds				Increase per acre in pounds			Increase per pound of element in pounds		
	Nitrogen	Phosphorus	Potassium	Total	Grains and straw	Hays	Total	Grains and straw	Hays	Total
Horse manure......	52.8	8.3	48.2	109.3	1,064	732	1,796	9.7	6.7	16.4
Cattle manure......	68.4	15.4	52.4	136.2	1,286	650	1.936	9.4	4.8	14.2
Chemicals—N P K..	37.5	8.4	23.9	69.8	946	192	1,138	13.6	2.7	16.3
Chemicals—N P....	37.5	8.4	—	45.9	655	70	725	14.3	1.5	15.8
Chemicals—P K....	—	8.4	23.9	32.3	686	295	981	21.2	9.1	30.3
Chemicals—N K....	37.5	—	23.9	61.4	511	76	587	8.3	1.2	9.5
Chemicals—P......	—	8.4	—	8.4	352	191	543	41.9	22.7	64.6
Chemicals—N......	37.5	—	—	37.5	190	30	—160	5.1	—.8	4.3
Chemicals—K......	—	—	23.9	23.9	264	45	309	11.0	1.8	12.8

composition of the manure must be made before it can be credited with any superior effectiveness over chemical fertilizers of equivalent composition.

During the first nine years of the five-year rotation sulfate of ammonia was used as the chemical carrier of nitrogen, which would have given manure an advantage because of the lime it contains. Moreover, the comparison of chemicals shows that this soil is especially responsive to potassium, and after all reasonable allowance has been made for losses the manures must have carried a much larger proportion of this element than the chemicals.

The Indiana station calls attention to the fact that nitrogen has been given in excessive quantities in the longer rotation, as shown by the relatively large increase from phosphorus and potassium without nitrogen.

Table 17 shows that a much larger proportion of the effect of the chemicals than of the manures has been realized in the grain crops, leaving a comparatively small amount to be carried over to the hays.

SUMMARY

It will be observed that the foregoing discussion has been limited to the management of ordinary farm crops. That of truck crops, especially those in which much of the root growth is removed from the soil, is a separate proposition. Moreover, crops of high acre value will justify systems of treatment that would be impracticable on farm crops.

Considering both duration of test and yield per acre, the yield of wheat on Plat 8 in Broadbalk Field is the largest yield of wheat of which the world has any record, but this yield has been obtained without the addition of any organic matter except that contained in the roots and stubble of the crops.

In the continuously grown crops at Wooster the yields obtained on Plat 8, receiving chemicals only, are all above the average yields of the county in which the test is located, while the unfertilized yields show that the land was in a very low state of fertility at the beginning of the experiment. It was, in fact, part of a farm which had been subjected to the exhaustive methods of tenant husbandry for a quarter of a century.

From the well-known behavior of corn on soils rich in organic matter it would be expected that this crop would suffer most from the deprivation of this material, but the yield of corn continuously grown on Plat 6, with its 5 tons of manure every year, has fallen off as rapidly as that on the land receiving chemicals.

When these crops have been grown in rotation with clover, the yields have been maintained for 40 years in the Pennsylvania test at least as well by chemicals as by manure, and in all the Ohio tests the chemicals are showing at least equal effectiveness, pound for pound of elements contained, to the manures. In fact, in order to get as large a relative return from manure as from chemicals it has been necessary not only to reinforce the manure with phosphorus in order to meet the demands of soils from which the common system of agricultural practice has removed the phosphorus more rapidly than the nitrogen or potassium, but also to compute the nitrogen in manure at a lower rate than that indicated by chemical analysis, because of unavoidable losses of nitrogen in handling manure.

It does not seem that either chemicals or manures possess any regular superiority in unfavorable seasons; the results indicating that sometimes one, sometimes the other carrier is the more effective, depending upon the character of the season.

Where any greater residual effect has followed manure than chemicals it appears to be fully explained by the larger dosage of essential elements given in manure and by the slower action of these elements in manure than in chemicals. Such effect is therefore obtained at the sacrifice of immediate returns.

PRACTICAL APPLICATIONS

The experiments here reported show that it has been possible, by the use of chemicals alone, to maintain the yields of farm crops for periods of 20 to 30, 40, and 70 years on a parity with the yields from applications of farm manures containing much larger total quantities of the essential chemical elements, and therefore that the addition to the land of any organic matter for the sake of the carbonaceous material such matter may contain is altogether unnecessary; the outcome warranting the assumption that the larger root growth, which may be obtained as effectively from the elements in chemicals as from those in manure, furnishes all the organic carbon required for bacterial functioning.

It is recognized, as a matter of course, that soils high in organic carbon are usually fertile soils, and that the distribution of decaying vegetation through the soil favors its physical condition, but the fact has been too generally overlooked that no artificial distribution of vegetation through the soil is so perfect as the natural growth of plant roots, and that when sufficient nitrogen and mineral elements are supplied in available form, and the water supply is properly regulated, the plant will find all the carbon required and its roots will take care of the soil's physical condition.

When the farmer shall have come to look upon farm manure as simply a carrier of nitrogen, phosphorus, potassium, and lime (including calcium and magnesium) and shall have realized the certainty of loss of a considerable part of these elements from improper handling of the manure, the cost of replacing them, especially the nitrogen, when so lost, and the necessity for a readjustment of the ratio between the nitrogen and other elements, which has been brought about by the prevailing system of agriculture, he will place a much higher value upon manure than he now does. He will then avoid the losses that now occur in the barnyard and the waste that follows the application of manure in such large dressings that a large part of its most costly constituent—nitrogen—is lost because of lack of a sufficiency of phosphorus to balance its nitrogen.

It will of course be understood that where, in some of the foregoing comparisons, the elements in manure have been computed at the same cost as those in chemicals, the object has been simply to show their relative effect. On the farm the cost of the elements in manure should be much less than their cost in chemicals, although it is possible, by permitting manure to heat or to be leached until most of its value is lost, or by purchasing it at too high a price, or hauling it long distances, or otherwise expending unnecessary labor upon it, to make it a more expensive fertilizer than chemicals.

The same general principles apply to the use of other organic materials. To plow under a crop of clover, for example, may be a very expensive process when the rental of the land and the feeding or market value of the crop is considered. Clover adds nothing to the soil except nitrogen, its mineral elements being simply a turnover when it is plowed under. Moreover, it is not certain that all of its nitrogen is an addition, for when clover is grown on land supplied with nitrogen there is less evidence of the work of the nodule-forming bacteria. The root growth of clover, especially of sweet clover, is an incomparable pulverizer of the soil, and rye, grown as a catch crop, may be made of great service in this respect, but to permit the growth of either clover or rye to continue until late in the spring before turning it under sometimes so depletes the soil of water as to injure instead of benefitting the succeeding crop.

METHOD NOW EMPLOYED IN TESTING F_1 CORN HYBRIDS AT THE CORNELL UNIVERSITY AGRICULTURAL EXPERIMENT STATION[1]

R. G. WIGGANS[2]

The large increase in corn breeding work due to the development of the inbreeding method has presented to investigators the problem of adequately testing the large number of F_1 hybrids resulting from the crosses of many inbred strains, particularly where crosses between strains of different varieties are given considerable attention. Invariably the investigator has been limited in his testing by the space and labor available for the work. This phase of the problem has presented itself very forcibly at the Cornell University Experiment Station, and as a result the method outlined below has been worked out whereby a fairly economic use is made of the land allotted to the investigation. The method is described here as one which is giving good results at this station with the hope that it may be of aid to investigators who are experiencing similar difficulties, and not necessarily as an ideal way of testing.

METHOD OF TESTING

To make testing as simple as possible, an uncomplicated and orderly system of numbering is necessary. The system used at this station in the inbreeding and re-crossing work includes both the strain number and the year number. For example, the numbers for 1925 were 25–1, 25–2, 25–3, etc.; those for 1926: 26–1, 26–2, 26–3, etc. By this system the pedigree numbers are always comparatively small, the age of the seed is easily determined, and simplicity in storage is secured. Cards are used for the complete records of any strain or cross.

The testing of the many F_1 crosses is made difficult not only by the lack of labor and space available, and in some cases the small amount of seed, but also by the possibility of competition between adjacent plantings. Especially is competition important if inbred strains are grown alongside either the parent varieties or the F_1's, or if the parent varieties are grown alongside the F_1's. The first two difficulties are overcome partially by small unit plantings, while the third problem makes it necessary, or at least highly desirable, to grow parent varieties alongside other parent varieties possessing approximately the

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same general characters, and F_1's alongside other F_1's, unless larger plats are grown, which is in most cases inadvisable or impossible.

These difficulties are to some extent overcome by the plan of testing outlined in Table 1.

By this system inbred strains are in competition only with inbred strains; commercial varieties with commercial varieties; and F_1's with F_1's. At the same time a close comparison can be made between the F_1 and the commercial varieties from which the inbred strains were derived, a fairly close comparison with the inbred strains, and a comparison of the commercial varieties and the inbred strains derived from them. Competition within the sections is reduced to a minimum by growing similar types adjacent one to the other. In some cases, where several crosses are made with one inbred strain, blocks of considerable size can be planted to the same thing, as illustrated in Sections A and B in the table. Probably the only hills affected by competition to any extent are the end hills between Sections A and B and in a few cases between B or D and C when one parent variety happens to be much smaller or otherwise different from the F_1. The number of repetitions of any one cross is usually restricted by the amount of seed and the space available. The number used in the preliminary tests at this station has been four. The system permits of unlimited expansion and different numbers of repetitions. The number of hills in each section should be rather small if this system is employed. The larger the number of hills the greater the amount of variation introduced, since the comparisons are made between rows placed end to end. The smaller number of hills per section likewise permits of a larger number of replications with the same amount of seed, labor, and land. The unit used in these tests has been six hills. It is assumed in following this plan that the greater variation introduced by the end to end comparison is of less importance than the effect of competition when types differing considerably are grown side by side.

In order to eliminate variation in stand as much as possible, thick planting with subsequent thinning is practiced. Harvesting is done by series as far as possible, green weights being taken in all cases and at least two shrinkage samples retained for later drying and for determining the amount of grain. The average dry weight of these two samples is used for calculating the dry weights of the several replications. It is realized that sampling every row or the securing of a composite sample would be a better method, but the increased physical difficulties seem hardly justified for the slightly more accurate determination.

TABLE 1.— *Showing partial plan of planting for F_1 test for 1925.*

	Section				
	A	B	C	D	E
Row numbers	Inbred strain of one commercial variety	Commercial variety	F_1 of inbred strains	Commercial variety	Inbred strain of other commercial variety
1-301-601-901	24-110	Luce's Favorite	24-110 x 24-140	Cornell 11	24-140
2-302-602-902	24-110	Luce's Favorite	24-110 x 24-163	Alvord's White Cap	24-163
3-303-603-903	24-110	Luce's Favorite	24-110 x 24-189	Onondaga White Dent	24-189
4-304-604-904	24-110	Luce's Favorite	24-110 x 24-300	U. S. No. 193	24-300
5-305-605-905					
6-306-606-906					
7-					
8-					
etc.					

METHOD OF INTERPRETING THE RESULTS

Since the chief object of such a test as this is to eliminate all crosses which do not show a significant gain, not only over the average of the parent varieties but also over the better variety, the method of interpreting the results obtained is of equal importance with the layout of the experiment. The procedure followed in this test, in order to determine the F_1's which are significantly better than the parent varieties, is to assemble all data of one cross as follows:

1925 F_1 TEST

Onondaga White Dent 24–96 x 24–442 Webber's Dent.

		Green weight		Dry weight		Percentage dry weight		Dry weight row	
Section	Row	Total	Sample	Total	Grain	Total	Grain	Total	Grain
A[a]	89	19.5						4.5	1.3
	187	17.3				23.0	28.2[f]	4.0	1.1
	276	20.7						4.8	1.4
	352	16.2						3.7	1.0
		18.4±.69						4.2±.17	1.2±.06
B[b]	89	27.5						6.8	2.3
	187	28.5				24.6	33.1[f]	7.0	2.3
	276	24.5						6.0	2.0
	352	27.0						6.6	2.2
		26.9±.57						6.6±.15	2.2±.05
C[c]	89	28.9	14.5	3.65	1.5	25.2	41.1	7.4	3.0
	187	29.9	16.15	4.2	1.65	26.0	39.3	7.7	3.1
	276	35.0				—	—	9.0	3.6
	352	27.0				25.6	40.2	6.9	2.8
		30.2±1.15						7.7±.30	3.1±.11
D[d]	89	23.2						6.0	2.2
	187	16.3				25.8	36.2[f]	4.2	1.5
	276	25.0						6.4	2.3
	352	18.3						4.7	1.7
		20.7±1.38						5.3±.35	1.9±.13
E[e]	89	19.1						3.9	1.0
	187	16.9				20.2	26.4[f]	3.4	.9
	276	19.6						4.0	1.1
	352	13.9						2.8	.7
		17.4±.88						3.5±.19	.9±.06

[a] Inbred strain of one commercial variety.

[b] Commercial variety from which inbred strain in Section A was derived.

[c] F_1 of inbred strains.

[d] Commercial variety from which inbred strain in Section E was derived.

[e] Inbred strain of commercial variety in Section D.

[f] Determined from average of dry weights of shrinkage samples taken elsewhere for the variety or strain.

When all the data are assembled in this way, various comparisons can be easily made (1) by the calculation of the means with their probable errors, from which the differences with their probable errors can be obtained, or (2) by the pairing method in which the Z value is calculated and the odds read either from Student's or Love's tables for estimating the probability that the difference between two series is significant.

By the first method C is greater than B by 3.3 ± 1.28 in total green weight; 1.1 ± .34 in total dry weight; and 0.9 ± .12 in dry weight of grain; and greater than D by 9.5 ± 1.80 in total green weight; 2.4 ± .46 in total dry weight; and 1.2 ± .17 in dry weight of grain.

The second method has been used generally in these tests where the significance or non-significance was not apparent from direct observation of the data. By this method, in the above illustration C is greater than B in total green weight by odds of 7 : 1; in total dry weight by odds of 10 : 1; and in dry weight of grain by odds of 65 : 1; and greater than D in total green weight by odds of 203 : 1; in total dry weight by odds of 171 : 1; and in dry weight of grain by odds of 322 : 1.

Thus it is concluded that the F_1 from 24-96 x 24–442 is not significantly better in production of total green weight or total dry weight but is significantly better in grain production than the better of the parents from which the inbred strains were derived. It is further concluded that the F_1 is significantly better in total green weight, total dry weight, and dry weight of grain than the poorer of the two parent stocks. The significant differences between the parent stocks and the inbred strains derived from them are apparent by either method of comparison.

STUDIES ON INOCULATED SOYBEANS: I. THE IMPORTANCE OF DETERMINING THE NUMBER AND SIZE OF SOYBEAN NODULES FOR EVALUATING RELATIVE EFFICIENCIES OF TWO OR MORE CULTURES[1]

Lewis W. Erdman[2]

In testing the efficiency of different cultures for the inoculation of soybeans at the Iowa Experiment Station, one of the first problems which demanded attention was that of devising a suitable classification of the inoculated plants for designating the various intensities or degrees of nodulation. The need of such a classification is apparent after a glance at the literature on soybean inoculation. With reference to numbers of nodules such terms as few, very few, numerous, large and numerous, small but numerous, very large and numerous, several scattered nodules, and sparse nodule formation are commonly found. With reference to the degree of inoculation such terms are recorded as fair, good, and very good, but more frequently either inoculated or uninoculated is used. In some cases the number of nodules per plant is given, together with the average number per plant, but no mention is made of the size. In other instances the number of nodules is divided into two groups, namely, large and small.

The great variation in size and numbers of nodules on soybean plant roots is familiar to everyone. It seems, however, judging from the literature, that the real significance between different sizes of soybean nodules has been greatly underestimated. Therefore, the first step was to establish, if possible, a definite relationship between nodules that vary markedly in size. Such information would tend to show whether or not the terms mentioned above are justified, and furthermore would possibly suggest a more accurate means of differentiating relative efficiencies of two or more cultures.

EXPERIMENTAL WORK

Manchu, Dunfield, Peking, and Midwest soybeans were the four varieties that were used in this work. Each variety was planted the same day, but the nodules were not collected from the roots until small beans had formed in the pods. Nodules were thus secured from the Manchu and Dunfield soybean roots about August 25, 1925, and from the Peking and Midwest plants about September 25, 1925.

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[1] Contribution from the Soil Bacteriology Laboratories, Iowa Agricultural Experiment Station, Ames, Iowa. Received for publication May 24, 1926.

[2] Assistant Professor of Soils and Assistant Chief in Soil Bacteriology.

No record was kept of the number of plants that were dug to secure the nodules, since the object of this part of the work was to obtain a sufficient quantity of different sizes to determine an accurate average for each group. For convenience in separating the different sizes in the field, the nodules were placed in three arbitrary groups, small, medium, and large. Each nodule was washed thoroughly with water and the aid of a small hand brush to remove all traces of soil, then spread out and allowed to air-dry in the laboratory. The total number in each group was counted, then weighed on an analytical balance, after which they were pulverized to a fine powder in an iron mortar. The samples from each group for each variety were analyzed for total nitrogen by the Gunning method. Moisture determinations were made on the air-dry samples and the final results were calculated on the oven-dry basis. The results of this study are presented in Table 1.

TABLE 1.—*Showing the number, size, weight, and total nitrogen content of soybean nodules from four varieties.*

Lab. No.	Variety	Size of nodules	Number of nodules	Total weight of nodules *Grams*	Average weight of each nodule *Mgs.*	Total nitrogen *%*	Average amount nitrogen in each nodule *Mgs.*
1	Midwest	Small	500	3.4254	6.8	4.10	0.2788
2	Midwest	Medium	120	6.1069	50.8	3.87	1.9659
3	Midwest	Large	150	14.5005	96.6	3.55	3.4293
4	Peking	Small	269	4.0010	13.5	3.81	0.5143
5	Peking	Medium	319	15.3587	48.1	3.98	1.9143
6	Peking	Large	85	9.7030	114.1	3.65	4.1646
7	Dunfield	Small	500	4.3380	8.6	4.95	0.4257
8	Dunfield	Medium	290	12.9307	44.5	4.90	2.1805
9	Dunfield	Large	140	13.4727	96.2	4.83	4.6464
10	Manchu	Small	500	4.0936	8.1	4.69	0.3798
11	Manchu	Medium	368	16.1521	43.8	5.01	2.1943
12	Manchu	Large	105	10.0469	95.6	4.43	4.2350

DISCUSSION OF RESULTS

Although the total number of nodules of the different sizes which were used varied considerably for each variety, the average weight of each nodule in the small, medium, and large groups was very nearly the same for all four varieties. Exceptions to this statement may be noted in the case of the small and large Peking nodules. These sizes were a little harder to find on the Peking plants, and it is possible that had a greater number been used the averages would have been more uniform. The average weight of each group for all four varieties was 9.25 mgs. for the small size, 46.8 mgs. for the medium size, and 100.6 mgs. for the large size. On this basis it would take approximately five small nodules to equal one medium nodule, and approximately ten small ones to equal one large nodule. Likewise one large nodule would be approximately equivalent to two medium sized nodules.

The Manchu and Dunfield nodules were considerably higher in percentage of total nitrogen than those of the Peking and Midwest varieties. This may have been due to the fact that they were gathered a month earlier, and consequently did not have the chance to give up as much nitrogen to the plants as those nodules which were in contact with the plants one month longer. In some further work at this station it is hoped that data will be obtained which will show the nitrogen content of different sized nodules from different varieties at different stages of maturity of the soybean plants.

By examining the data in Table 1 it will be noted that there was very little difference in the percentage of total nitrogen for the small and medium sized nodules. In every case, however, there was a decided decrease in the percentage of total nitrogen for the large nodules. It is surprising that these differences were not even greater for the large nodules.

The data presented in the table showing the average amount of nitrogen in each nodule afford very convincing evidence to strengthen the supposition that there is a rather significant difference between small, medium, and large soybean nodules. The relation between the average amount of nitrogen in each nodule for the three groups for all four varieties was very similar to the average weights of the small, medium, and large nodules. Especially was this true for the medium and large sizes. In this case one large nodule contained 1.99 or approximately two times as much nitrogen as one medium nodule. A single large nodule contained 11.2 times as much total nitrogen as one small nodule. One medium sized nodule contained 5.6 times as much nitrogen as one small nodule. Thus, as was true with the average weights for each nodule in the three groups, the greatest difference in total nitrogen content lies between the small and medium and the small and large sizes. It is, therefore, of greater importance to distinguish between these sizes, although it would be very desirable to distinguish between the medium and large sizes as well. It seems from the data and discussion which have been presented that in determining the relative efficiency of two or more cultures for the inoculation of soybeans, the importance of recording the number and sizes of the nodules with the average weights for each different size can not be emphasized too strongly.

Using the average weights of the nodules of the different sizes of each variety as a basis upon which to work, that is one large nodule being approximately equal to two medium or ten small nodules and one medium nodule being equal to five small ones, the following classification of inoculated soybean plants is suggested for differentiating degrees or intensities of nodulation:

Class No.	Number and size of nodules per plant
0	No nodules present
1	1 to 5 small nodules
	1 medium
2	6 to 10 small
	1 medium + 1 to 5 small
	2 medium
	1 large
3	11 to 20 small
	1 medium + 6 to 15 small
	2 medium + 1 to 10 small
	3 medium + 1 to 5 small
	4 medium
	1 large + 1 to 10 small
	1 large + 1 medium + 1 to 5 small
	1 large + 2 medium
	2 large
4	21 to 30 small
	1 medium + 16 to 25 small
	2 medium + 11 to 20 small
	3 medium + 6 to 15 small
	4 medium + 1 to 10 small
	5 medium + 1 to 5 small
	6 medium
	1 large + 11 to 20 small
	1 large + 1 medium + 6 to 15 small
	1 large + 2 medium + 1 to 10 small
	1 large + 3 medium
	1 large + 3 medium + 1 to 5 small
	1 large + 4 medium
	2 large + 1 to 10 small
	2 large + 1 medium + 1 to 5 small
	2 large + 2 medium
	3 large
5	31 to 40 small
	1 medium + 26 to 35 small
	2 medium + 21 to 30 small
	3 medium + 16 to 25 small

Class No.	Number and size of nodules per plant
5	5 medium + 11 to 20 small
	5 medium + 6 to 15 small
	6 medium + 1 to 10 small
	7 medium + 1 to 5 small
	8 medium
	1 large + 21 to 30 small
	1 large + 1 medium + 16 to 25 small
	1 large + 2 medium + 11 to 20 small
	1 large + 3 medium + 6 to 15 small
	1 large + 4 medium + 1 to 10 small
	1 large + 5 medium + 1 to 5 small
	1 large + 6 medium
	2 large + 11 to 20 small
	2 large + 1 medium + 6 to 15 small
	2 large + 2 medium + 1 to 10 small
	2 large + 3 medium + 1 to 5 small
	2 large + 4 medium
	3 large + 1 to 10 small
	3 large + 1 medium + 1 to 5 small
	3 large + 2 medium
	4 large
6	All plants showing a greater number of different sized nodules than listed in class 5.

This plan of grouping inoculated plants would include all degrees of nodulation which have been encountered in the soybean inoculation experiments on different types of soil near Ames, Iowa.

In using this scheme of classification it is realized that a tremendous amount of careful work will be involved. At the same time, however, results obtained in this manner will have a definite meaning to others who are interested in the work.

It is hoped that this classification may stimulate other suggestions which will lead to a more exact terminology or nomenclature for distinguishing between not only relative efficiencies of different cultures, but also between the effects of various cultural and fertilizer treatments on the inoculation of soybeans.

SUMMARY

In 1925 different sized nodules were collected from Manchu, Dunfield, Peking, and Midwest soybeans. These nodules were divided into three groups according to size, namely, small, medium, and large. They were washed, dried, counted, and weighed, after which they were ground to a fine powder and analyzed for total nitrogen. Sufficient data were obtained to establish a definite relationship between the nodules of small, medium, and large sizes;

and the importance of determining the number and size of nodules in studies on inoculation of soybeans was emphasized. A scheme of classification of the different degrees or intensities of nodulation on soybean plants based upon the results obtained in this study was suggested.

It is concluded from the results of this study that the relative efficiency of two or more cultures for the inoculation of soybeans can be accurately determined only after the number and different sizes of nodules have been ascertained.

BREEDING WINTER OATS FOR THE SOUTH[1]

T. R. STANTON[2]

INTRODUCTION

The systematic breeding of winter oats by the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, was begun in 1904, in cooperation with the Maryland Experiment Station. This work was transferred to the Arlington Experiment Farm, Rosslyn, Va., in 1907, where a fairly efficient nursery for the isolation and determination of winter-resistant strains of oats has been maintained to the present date. During the earlier years work was confined almost entirely to the collecting of varieties from both domestic and foreign sources, the determination of their adaptation and the making of pure-line selections from them. Since 1915, some attention has been given to improvement by hybridization, particularly in breeding for cold resistance. To discuss briefly such progress as has been made in these investigations and to emphasize a few of the outstanding accomplishments, is the major purpose of this paper.

NURSERY METHODS

Since 1921, the breeding work with winter oats at the Arlington Experiment Farm has been conducted in accordance with a more or less standardized nursery system. Three different series of nursery rows are employed. These include (1) 5-foot head or plant rows; (2) duplicated 15-foot rows; and (3) duplicated blocks or plats of three

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[1] Paper read by title before the section of agronomy at the twenty-seventh annual convention of the Association of Southern Agricultural Workers held at Atlanta, Ga., February 3-5, 1926. Received for publication May 28, 1926.

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15-foot rows each. In the system employed the better strains are advanced from one of these series to another. The most promising initial pedigreed strains from plant rows are advanced to the duplicated 15-foot row nursery solely on their merit as determined by inspection and study. Inferior strains in plant rows are immediately discarded unless retained for some special breeding purpose. The number of years a strain is carried in either the duplicated 15-foot row nursery or in the duplicated three-row plat nursery, depends entirely on its agronomic behavior with regard to cold resistance, yield, purity of type, etc. If a strain shows exceptionally desirable characteristics, it is usually placed in the latter nursery after one year's test in the former in which the final value of a strain is thus largely determined. Only the very best strains ever reach this latter nursery. Smaller differences between strains in yield, resistance to lodging, quality of grain, etc., necessarily must be taken into consideration. From this nursery, then, the few outstanding promising sorts are advanced to the varietal experiments in field plats.

The number of replicated plantings in 15 foot rows, as well as in the three-row plats, may be increased as desired, with a corresponding increase in nursery efficiency. However, the amount of work involved increases with the number of replications. Further replication at the Arlington Experiment Farm has not been possible, mainly because of limited space and the necessity of reducing labor cost to the minimum. Ordinarily, about 500 strains in plant rows, 200 in duplicated 15-foot rows, and 100 in duplicated plats of three 15-foot rows each are grown annually.

In the harvesting of the three-row plats the amount of work may be reduced by using only the middle row. In fact, this practice is followed at a number of experiment stations. So far, all three rows have been harvested at the Arlington Experiment Farm in order to make some study of the factor of varietal competition. At that station also, all rows are sown 18 feet in length and trimmed to 15 feet at harvest. This serves to eliminate border effect due to the unplanted alleys. Likewise, the computing of yields is simplified as the weight of grain in grams per row multiplied by 0.2 equals the yield in bushels per acre.

RESULTS OF PURE-LINE BREEDING

During the past 15 years many varieties and strains of oats have been grown and observed in the breeding nursery at the Arlington Experiment Farm. Naturally, of so large a number many have been discarded. Only those showing some degree of winter resistance have been retained. From these hardier sorts numerous plant or head selections have been made and grown. Practically all the older selections which are still being continued in nursery experiments were made by C. W. Warburton, formerly agronomist in charge of oat investigations of the Office of Cereal Crops and Diseases. The varieties pedigreed in these early investigations were represented mostly by such types as Culberson, Red Rustproof, and Winter Turf. Some of these strains have been of special merit. As an example, two Winter Turf selections, C. I. Nos. 435-4 and 541-4, may be cited. These strains have now been grown since 1916 in duplicated or triplicated twentieth- or fortieth-acre plats. During the 10-year period from 1916-1925, inclusive, they have given average yields of 63.9 and 63.3 bushels, respectively. During this period the best unselected Winter Turf strain, C. I. No. 431, has averaged only 55.7 bushels. Culberson, C. I. No. 273, the check variety, has averaged 55.5 bushels. It thus will be seen that during this period these selections have shown an increase over the unselected Winter Turf of about 8 bushels to the acre.

Another improvement accomplished by selection has been in the breeding of Fulghum oats at the Arlington Experiment Farm. During the harvest of 1920, 31 selections were made from three different strains of Fulghum, C. I. Nos. 650, 699, and 708. The strain, C. I. No. 708, has been included in the varietal experiments in field plats at the Arlington Experiment Farm since 1913. The original seed was obtained from Judge Henry C. Hammond, of Augusta, Ga., through whom also the history of the Fulghum variety was obtained.[3]

The selections were sown in 5-foot plant rows in the fall of 1920. Brief notes were made on these plant rows that same fall. It was observed that the young plants of several of the selections showed a decided spreading or winter habit of growth. The leaves were narrower and of a darker green than those of the Fulghum parent. It also was noted that some of these strains showed unusual tillering capacity. The following summer most of these strains ripened from three days to a week later than the parent strains, C. I. Nos. 650, 699, and 708. In kernel characters they were distinctly Fulghum in type, although there was some variation in size and length of kernel. (See Fig. 1.) Because of rather outstanding characteristics, 21 of these selections were advanced to the 15-foot nursery rows where they were grown during the crop year 1921-22. Since 1922, the best of these selections have been grown in the duplicated three-row block nursery. The Fulghum selections, as a group, have proved so promising that all of them were placed in the duplicated three-row block nursery in the fall of 1925. The yields obtained from seven of the winter-type Fulghum strains in nursery experiments in comparison with one of the parents and other strains are shown in Table 1.

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[3] STANTON, T. R. Fulghum oats. U. S. D. A. Circ. 193:2-11. 1921.

TABLE 1.—*Annual and average acre yields of six winter-type Fulghum strains and three typical Fulghum strains grown in nursery rows at the Arlington Experiment Farm, during the four-year period, 1922–25, inclusive.*

C. I. No.[a]	Variety	Acre yield in bushels					
		1922	1923	1924	1925	Average 1923–25	Average 1922–25
	Fulghum selections with spreading habit of plant in early growth						
699–2011	Fulghum	96.0[b]	79.3	63.3	92.3	78.3	82.7
699–209	Fulghum	95.0[b]	72.7	62.9	79.2	71.6	77.5
699–2015	Fulghum	96.0[b]	72.7	51.6	89.2	71.2	77.4
699–202	Fulghum	87.6[b]	74.1	56.5	87.1	72.6	76.3
650–203	Fulghum	94.4[b]	69.5	57.1	79.3	68.6	75.1
708–204	Fulghum	93.6[b]	67.0	52.7	86.0	68.6	74.8
Average		93.8	72.6	57.4	85.5	71.8	77.3
	Fulghum strains with semispreading to erect habit of plant in early growth						
708	Fulghum	86.1	79.9	64.4	77.0	73.8	76.9
839	Kanota	87.8	78.6	56.7	75.2	70.2	74.6
850	Fulghum (King of Etheridge)	76.9	80.6	51.4	74.2	68.7	70.8
Average ..		83.6	79.7	57.5	75.5	70.9	74.1

[a] Cereal Investigations accession number.

[b] Yield obtained from single 15-foot row.

The data presented in Table 1 show that as a group the selected strains of Fulghum are slightly superior in yield to the unselected parents. The crop seasons of 1921–22 and 1924–25 were especially favorable to the selections, and some of them outyielded the parent strains as much as 10 bushels to the acre. In 1922–23, the difference in average yields was decidedly in favor of the parent strains, while in 1923–24 the parents and the selections produced practically identical average yields.

The data recorded for winter survival (estimated and not determined by exact counts) are interesting in connection with the yield results. During the winter of 1921–22, the stands of the original strains (C. I. Nos. 650, 699 and 708) were reduced about 25% by freezing, while the survival of the selections was practically 100%. In the season of 1922–23, practically no winterkilling occurred in any of the Fulghum strains, the lower yields of the selections being due to soil inequality or other cause. The next season, 1923–24, some slight winterkilling in the parent strains was noted, yet they equalled the selections in average yield. All strains were recorded as surviving practically 100% in 1924–25, when the selections again decidedly outyielded the parent strains.

From Table 1 it will be noted further that selection C. I. No. 699–2011 has been consistently the highest yielder. It is of interest to add that this selection was grown in a one-fortieth-acre field plat in 1924–25 and produced a yield of 91 bushels to the acre, as compared with 60 bushels for Fulghum, C. I. No. 708. Another selection, C. I. No. 650–203, also was grown in a similar plat with a yield of 71.9 bushels. These results in addition to those shown in Table 1 indicate the possibilities for improvement by selection within Fulghum, particularly in so far as the development of pure-breeding winter types of the variety is concerned. It is evident that Fulghum as it is now grown, is exceedingly variable, and that both spring and winter types may be selected from it. Further investigations may prove it to be almost as variable as the Burt variety, the great variability of which has been shown by Coffman, Parker, and Quisenberry.[4]

While no exceptionally cold and unfavorable winters have been experienced during the time these selections have been under test at the Arlington Experiment Farm, their prostrate growth habit in the early life of the plant indicates that they are without doubt rather distinct winter types. They also apparently possess greater cold resistance than the original Fulghum.

RESULTS OF HYBRIDIZATION

Excellent results have been obtained from a hybrid between Winter Turf and Aurora. The Winter Turf is the hardiest and most distinct winter oat, but has not been satisfactory in the area to which it is best adapted because of its very late maturity, weak straw, and poor kernel characters. The Aurora is more distinctly a spring oat which originated as a selection from Red Rustproof. The variety has been grown at the Arlington Experiment Farm from fall sowing. It is not particularly winter resistant, and usually produces high yields following mild winters only. However, its earliness and excellent kernel and straw characters are most desirable.

During the summer of 1915, the writer made a number of cross pollinations between these varieties. About 50 seeds were obtained some of which proved to be selfs. The F_1 plants were grown in pots in the greenhouse at the Arlington Experiment Farm in the winter of 1915–16. In the fall of 1916 seed from each of these plants was sown in 5-foot nursery rows. Owing to unfavorable weather conditions during the winter of 1916–17 and to weed growth the following spring, a large percentage of this hybrid material was destroyed. The few remaining plants were harvested and the seed from them was sown in the fall of 1917. As a result of the very cold winter which followed these hybrid strains again suffered even more severely from winterkilling. As in the previous year, the few surviving plants were saved and plant populations were grown from them during the more favorable crop years of 1918–19 and 1919–20. After continued testing several of the strains proved to be of sufficient promise to warrant sowing them in the three-row block nursery in the fall of 1920, where a number of them have been continued to date.

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[4] Coffman, F. A., Parker, J. H., and Quisenberry, K. S. A study of variability in the Burt oat. *In* Jour. Agr. Res., 30:1–64, illus. 1925.

Owing to the loss by freezing of a large percentage of the F_2 and F_3 plants during the winters of 1916–17 and 1917–18, it was not possible to make any definite genetic study of these hybrids. It is believed, however, that the unusual severity of these seasons was a distinct advantage in the isolation of the hardier segregates from these hybrids. The behavior during the past five years of the selections which have been continued indicates that natural selection probably played an important rôle in their development. Even as early as 1920 it was evident that the cold resistance of the Winter Turf variety had been combined with the earliness and excellent kernel characters of the Aurora to a very satisfactory degree. Most of the hybrid selections are a week to 10 days earlier than the Winter Turf, and produce the short, plump kernels of the Aurora. In bushel

TABLE 2.—*Annual and average acre yields of five Winter Turf-Aurora hybrid selections, the two parent varieties, and the highest yielding Winter Turf selection grown in nursery experiments at the Arlington Experiment Farm during the five-year period, 1921–25, inclusive.*

C. I. No.[a]	Variety	Acre yield in bushels					
		1921	1922	1923	1924	1925	Average
	Hybrid strains						
2042	Lee (1001 f1–1B)	73.0	84.4	65.7	47.7	88.0	71.8
2041	Custis (1001 d1–1B)	57.6	80.4	62.3	46.4	80.7	65.5
....	1001 h1–4–5B	65.0[b]	75.4	63.3	53.0	92.1	69.8
....	1001 f1–1B8	...	80.0[b]	76.4[b]	64.1	88.1	77.2[c]
....	1005 a4–18B[d]	43.2[b]	77.8	50.8	32.2	59.1	52.6
	Parent strains and the highest yielding Winter Turf selection						
831	Aurora	65.7	83.4	56.3	55.0	45.9	61.3
435	Winter Turf	66.3	68.9	69.4	50.9	71.6	65.4
435-4	Winter Turf selection	70.2	68.5	77.0	48.3	75.6	67.9

[a] Cereal Investigations accession number.

[b] Yield of single 15-foot row only.

[c] Four-year average.

[d] A Winter Turf-Aurora cross made in 1916.

weight many of the selections equal the Aurora parent, which variety in favorable seasons frequently produces grain weighing 38 pounds to the bushel.

The annual and average nursery yields obtained from five of the hybrid strains, together with the yields of the parent varieties, and the highest yielding Winter Turf selection at the Arlington Experiment Farm during the years 1921-25, inclusive, are shown in Table 2.

The data presented in Table 2 are indicative of the high yielding ability of these Winter Turf-Aurora hybrid strains. One of the selections has been named Lee and this is among the highest yielding, exceeding the Winter Turf selection, C. I. No. 435-4, by nearly 4 bushels to the acre, and the Winter Turf parent by 6.4 bushels. A companion strain, 1001 f1-1B8, has been even better than Lee, however, and has produced the high average yield of 77.2 bushels for the four years, 1922-25, inclusive. The strain 1005 a4-18B, represents a Winter Turf-Aurora cross made in 1916. As a group the selections of this cross are decidedly inferior in yield to those of the cross 1001 made in 1915. The yields of strain 1005 a4-18B are included in Table 2 primarily for comparison. The difference in yield between this strain and those of the previous series serves to emphasize the importance of crossing the right strains of varieties if real improvement is to be effected.

Owing to the exceptionally promising behavior of the Winter Turf-Aurora selections in nursery rows, a few of the best were sown in single fortieth-acre field plats at the Arlington Experiment Farm in the fall of 1921. The next season they were grown in triplicate one-fortieth-acre plats, and because of their continued promising per-

TABLE 3.—*Annual and average acre yields of Lee and Custis and five other varieties and strains of fall-sown oats grown at the Arlington Experiment Farm during the five-year period, 1922-25, inclusive.*

C. I. No.[a]	Variety	Acre yield in bushels				
		1922	1923	1924	1925	Average
	Winter Turf-Aurora selections					
2042	Lee (1001 f1-1B)	55.0	71.7	74.0	77.8	69.6
2041	Custis (1001 d1-1B)	68.4	69.1	69.0	67.0	68.4
2275	(1001 h1-4B)	57.1	70.0	66.8	67.3	65.3
	Parent and other varieties and selections					
831	Aurora	56.0	66.1	50.9	..	57.7[b]
708	Fulghum	68.7	66.4	49.9	66.0[c]	62.8
435-4	Winter Turf selection	62.4	61.3	81.5	57.3	65.6
431	Winter Turf (unselected)	57.0	57.4	70.9	52.0	59.3

[a] Cereal Investigations accession number.

[b] Three-year average. Not grown in field plats in 1925.

[c] Yield probably not comparable, due to variety being accidently mixed with another at time of seeding.

formance two of the most desirable have been named Lee and Custis. The annual and average yields of these two new varieties and one other Winter Turf-Aurora hybrid strain, as compared with similar yields of the Aurora parent, Winter Turf (C. I. No. 431 (unselected), Winter Turf selection (C. I. No. 435–4), and Fulghum grown in field plats at the Arlington Experiment Farm during the five-year period from 1922–25, inclusive, are shown in Table 3.[5]

The varieties Lee and Custis have maintained their high yielding power under field plat conditions. The results are equally as promising as those obtained from nursery experiments, and assuredly indicate that a decided improvement has been effected in the development of better oats for the northern portion of the winter-oat belt. Of the two, Lee has been the more uniform in plant and kernel characters. Custis has been less uniform. However, both are being reselected in order to establish definitely homozygous strains. Spikelets and florets of the Custis and Lee and the parent varieties are shown in Fig. 1.

VARIETAL PURITY

The maintenance of varietal identity is one of the most pertinent problems which confronts the oat producers of the South. The writer is not unmindful of the difficulty of retaining at a fair standard of purity such varieties as Fulghum and Red Rustproof, and the difficulty in differentiating between them from grain samples. Experience in collecting and receiving seed for identification and experimentation from various sources in the South has emphasized the importance and difficulties of the problem. Commercial samples of Red Rustproof frequently contain a mixture of Fulghum, while on the other hand Fulghum often contains some Red Rustproof. Other varieties also frequently are present.

It has been shown by pure-line selection that the Red Rustproof variety is homozygous and can be maintained in a uniform and pure condition by careful handling of the seed. Just why so much nondescript, so-called Red Rustproof oats are still grown in the South the writer has been unable to determine. There are available such well-known standard strains of Red Rustproof as Coker Appler, Hastings (Hundred Bushel), Patterson, Ferguson No. 71, and improved strains from experiment stations. These should replace the unselected and conglomerate strains of Red Rustproof which still are grown in many districts.

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[5] Credit is due John W. Taylor, Associate Agronomist in immediate charge of cereal experiments at the Arlington Experiment Farm, Rosslyn, Va., for the data presented in Table 3.

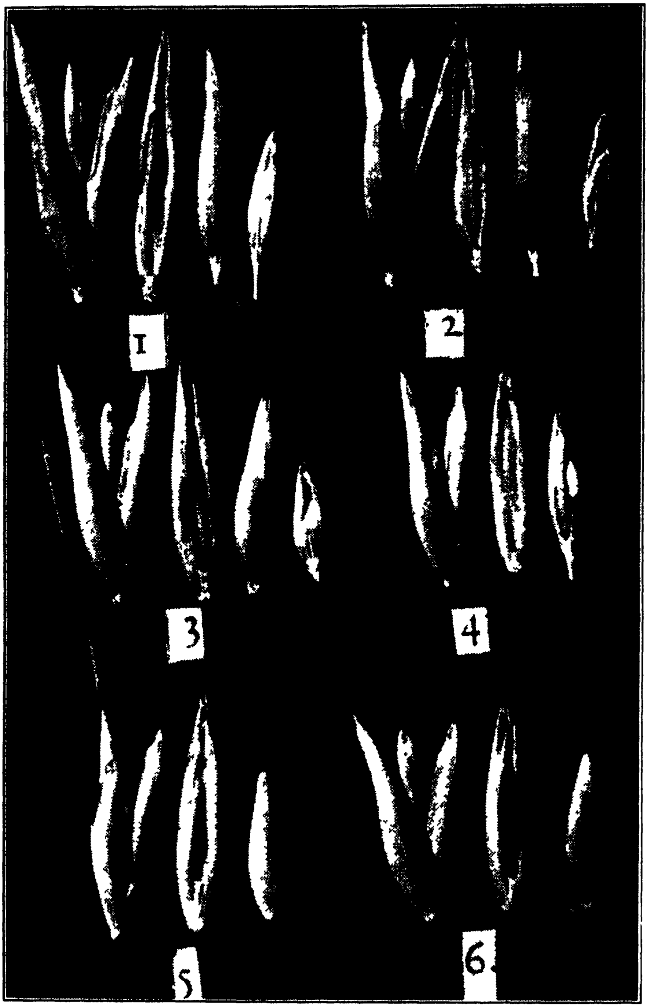

FIG. 1.—Spikelets and florets of six winter oat varieties and strains as follows: (1) Fulghum, C. I. No. 708; (2) Fulghum, C. I. No. 699-2011; (3) Lee; (4) Custis; (5) Winter Turf; and (6) Aurora.

Fulghum, on the other hand, does not possess the stability of type which characterizes the Red Rustproof oat. This variety frequently produces aberrant forms including the so-called "false wild." The most common aberrants are plants with off-colored kernels. The most numerous are black in color, although some plants produce gray, brown, or almost white kernels. Usually these aberrant plants are taller than those of typical Fulghum and can be removed by roguing. Fortunately, Fulghum has been decidedly more uniform as a fall-sown variety than when grown as a spring oat. Apparently, many of the aberrant forms are not hardy and do not survive when the variety is grown from fall seeding.

In field trips throughout the South the writer has found the so-called "false wild" form in many fields and plats. of Fulghum, but not so abundantly as seriously to decrease the value of the variety. The nature and origin of these wild-like forms are now being investigated at the Arlington Experiment Farm with the hope of determining the cause for their frequent occurrence in the Fulghum variety.

Work also is in progress at the Arlington Experiment Farm to breed hardier strains of red oats by hybridization, particularly of the Fulghum type. Several hundred selections from hybrids between Fulghum and such winter-hardy varieties as Culberson, Dwarf Culberson, Hatchett, and others are now being tested in nursery rows to determine their uniformity and relative yielding power. So far none of these strains has been as promising as the Fulghum selections previously discussed, although a number have produced very satisfactory yields and appear to be homozygous for most plant and kernel characters. Their value, however, for the most part yet remains to be determined.

LOOKING AHEAD IN WINTER OAT BREEDING

On the basis of accomplishments to date, particularly in improvement of winter oats by selection, it is probable that there is no other variety which offers greater possibilities along this line than Fulghum. The Office of Cereal Crops and Diseases has recently expanded considerably its work with this variety. During a brief survey of fields of oats in the vicinity of Tifton, Ga., in May, 1925, it was observed that many fields represented mixtures of varieties and strains, and that there appeared to be a real need for improved strains, especially of Fulghum. In addition to increasing the experiments with Fulghum at the Arlington Experiment Farm, 500 plant selections of this variety were sown at the Coastal Plain Experiment Station, Tifton, Ga., in the fall of 1925 in an attempt to develop superior strains particularly adapted to the southern portion of the cotton belt. Detailed descriptions of kernel color, type of spikelet and floret separation, awning and awn type, presence of basal hairs, etc., have been recorded for these selections. A study can be made, therefore, of the relationship between type of kernel and yield.

Red Rustproof also has a place in the cotton belt, and its improvement by selection should not be overlooked. There is need for better strains of this important variety than are now available. Unfortunately, the breeding experiments with Red Rustproof at the Arlington Experiment Farm have not been especially encouraging, mainly because of poor yields. This result is due largely to the fact that the vicinity of Washington, D. C., is north of the main range of adaptation of the Red Rustproof oat. Work with the variety should be undertaken within its proper range.

SUMMARY

A nursery for the isolation and development of cold-resistant, high-yielding, and otherwise desirable strains of winter oats has been maintained at the Arlington Experiment Farm since 1907.

A more or less standardized nursery system is used consisting of series of single 5-foot plant or head rows, duplicated 15-foot rows, and duplicated blocks or plats of three 15-foot rows each.

Two strains of Winter Turf, C. I. Nos. 435-4 and 541-4, have been developed which during the 10-year period, 1916–25, inclusive, have outyielded the unselected stock by about 8 bushels to the acre.

Definite winter types of Fulghum have been isolated and are being studied. In these forms the plants show a decided spreading or winter habit in early growth and have dark green, rather narrow leaves. The selections apparently are more cold-resistant, and are superior in yield to the original Fulghum.

Several high-yielding strains of winter oats have been developed from a Winter Turf-Aurora cross. In these strains the earliness and excellent kernel characters of the Aurora variety have been combined with the winter resistance of the Winter Turf oat to a highly satisfactory degree. Two of the most promising selections have been named Lee and Custis.

The maintenance of varietal identity in such standard oats as Fulghum and Red Rustproof is one of the most pressing practical problems in connection with the growing of oats in the South. Selected strains of these varieties are available and should be substituted for the nondescript, so-called Red Rustproof oats which are grown in many districts of the South.

The selection work with Fulghum was considerably expanded in the fall of 1925 at the Arlington Experiment Farm. In addition. 500 selections from Fulghum were sown at Tifton, Ga., for the development of strains especially adapted to the southern portion of the cotton belt.

Numerous selections from hybrids between Fulghum and hardy winter varieties, such as Culberson, Dwarf Culberson, and Hatchett, are being tested at the Arlington Experiment Farm to determine their winter resistance and yielding power.

INJURY FROM BURNING OFF OLD GRASS ON ESTABLISHED BLUEGRASS PASTURES[1]

L. F. GRABER[2]

Burning over pastures in the early spring is not only a common practice in some localities, but is quite generally recognized as being beneficial. Generally, it is regarded as having a stimulating effect on the early spring growth of perennial pasture grasses. Empirical information indicates that such burning should be done while the ground is still frozen, although much of it is not done until after thawing when the old grass may become sufficiently dry to burn readily.

On March 9, 1925, the writer burned the old accumulated grass of a bluegrass sod which had not been pastured the previous summer. The ground was still solidly frozen, but the grass burned very well, owing to extremely dry weather. The fire was extinguished along a certain line so that a contrast in the following growth between burned and unburned areas might be made. With the advent of warm growing weather, the burned area presented a very fresh, vigorous, green, lawn-like appearance, while in the unburned area, most of the early spring growth was hidden by the dry old grass which had accumulated during the previous summer. Observing this difference in appearance, the foreman of the experimental farm burned on May 11, 1925, another area, leaving a rod strip unburned between this and the March 9th burning. On May 11th, the ground was completely thawed so that in the experiment there were three areas, one burned on March 9th, while the ground was frozen, a rod strip not burned at all, and an adjacent area burned on May 11th. It may be added that the May 11th burning was made possible by the extreme drought which had not permitted much new spring growth in amongst the old grass. Part of these areas were pastured in 1925 and part were not pastured. During the early summer a very pronounced difference in the rate of growth of the grass was readily observable. The differences became intensified during the fall. On the May 11th burning, the grass was very short and this area became badly infested with such common weeds as witch grass, ragweed, and others. The area burned March 9th grew more vigorously and weeds were not so abundant. In the unburned area, there was a most luxuriant growth of grass. No weeds appeared. The difference in fall growth was very striking. These conditions prevailed in both the pastured and the unpastured parts of these plats. While no yields were taken in 1925, the old grass was removed from an area of 4 square feet the following spring, on April 21, 1926, before new growth had started and yields were computed as indicated in Table 1.

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[1] Contribution from the Department of Agronomy, Wisconsin College of Agriculture. Published by permission of the Director of the Wisconsin Agricultural Experiment Station, Madison, Wisc. Received for publication June 1, 1926.

[2] Professor.

TABLE 1.—*Effect of spring burning on following growth and root development of an established sod of a bluegrass pasture.*

Treatment	Yields of dry old grass in pounds per acre, April 21, 1926	Percentage decrease from burning in 1925	Dry weight of rhizomes and roots in pounds per acre to a depth of 7 inches, April 21, 1926	Percentage decrease from burning in 1925
Not burned...	3,944		10,582	
Burned May 11, 1925, soil completely thawed..	1,130	71.3	6,950	34.3
Not burned ..	4,497			
Burned March 9, 1925, surface of soil completely frozen..	2,140	52.4	6,975	34.0

The root growth to a depth of 7 inches on a similar area was also removed and freed from dirt by a careful washing process. Both top and root growths were dried, weighed, and computed on an acre basis. It will be noted from the data in Table 1, which were taken from the unpastured plats, that the old grass from the unburned area yielded 3,944 pounds, compared with 1,130 pounds for that from the area burned on May 11th. Another determination on the unburned area gave 4,497 pounds of old grass per acre compared with 2,140 pounds for the adjacent area which was burned on March 9, 1925, while the ground was still frozen. The May 11th burning decreased the yield as measured by the old grass 71.3% as compared with 52.4% decrease for the March 9th burning. It is admitted, of course, that in the unburned area may have been included some of the old grass left over from previous years. In other words, it cannot be assumed that all the grass collected on April 21, 1926, represented the growth made on the unburned area in 1925, whereas all the yield of the burned areas *was 1925 growth*—the old grass having been burned up. The very marked and observable difference, however, in the rate of growth in the burned and unburned plats does not make these comparisons appear too extreme.

FIG 1 — Spring burning of old grass injures bluegrass pasture. Late spring burning of dead grass in the above permanent pasture proved very harmful, as shown by the heavy summer and fall growth of weeds (in background) where the old grass was burned on May 11, 1925, after the frost was out of the ground In the foreground, where the old grass was left unburned, no weeds appeared and a heavy matted new growth of bluegrass occurred. In another test burning of the old growth while the ground was still frozen was injurious to the bluegrass, but much less so than later spring burning.

It is hardly believable that burning would have such an impressive effect as it did in this experiment A determination was also made on the amount of rhizome and root growth per acre from samples taken to a depth of 7 inches on an area of 4 square feet. On the unburned area, the dried roots and rhizomes yielded at the rate of 10,582 pounds an acre This, of course, included many rhizomes which may have been dead for a year or more without having completely disintegrated as well as other dead material and some stubble which could not be separated out The burned areas yielded 6,950 pounds and 6,975 pounds, respectively, for the May 11th and March 9th burnings, representing a reduction in rhizome and root development from burning of about 34%. The damage from burning, as measured by the top growth, was much more severe when done after the ground had thawed (May 11) than while the ground was still frozen (March 9). Just why the amount of root and rhizome should have been so nearly alike is difficult to explain. The pronounced reduction, however, in underground growth from both these burnings indicates that the rhizomes are, perhaps, injured to such a degree as to reduce the

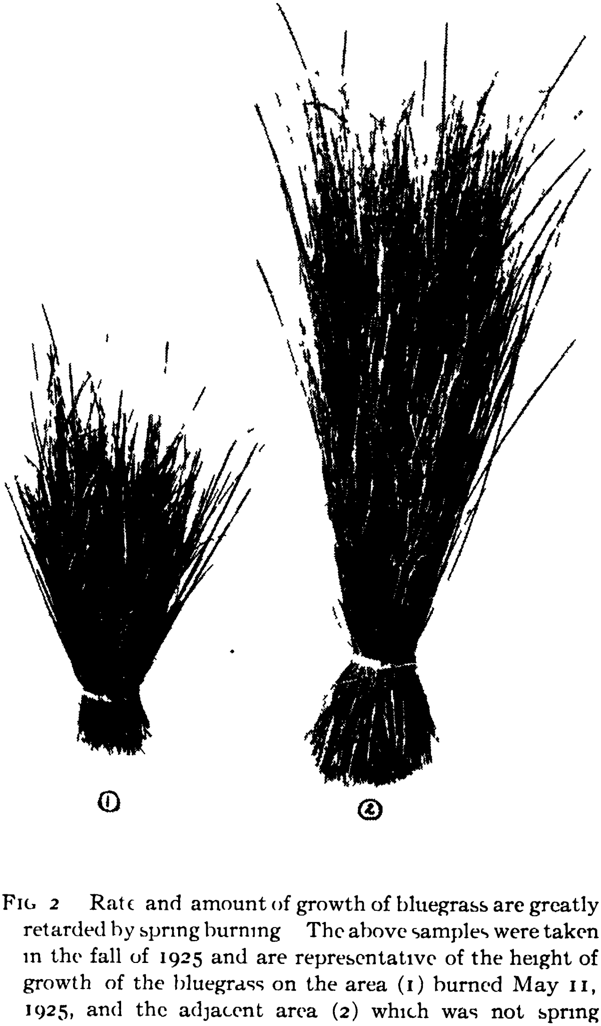

Fig. 2 Rate and amount of growth of bluegrass are greatly retarded by spring burning The above samples were taken in the fall of 1925 and are representative of the height of growth of the bluegrass on the area (1) burned May 11, 1925, and the adjacent area (2) which was not spring burned

amount of available food reserves which these rhizomes carry in storage for subsequent top growth and to reduce the root growth to a similar degree

Early this spring, 1926, the writer burned off other areas of this and other bluegrass pastures Again, the burning has seriously depressed the succeeding growth of the bluegrass in contrast to the adjacent areas unburned While no complete explanation of the harm from burning can be offered at this time, it does appear that so far as the amount of growth is concerned burning has a very injurious effect upon bluegrass pastures. In all probability, its supposed desirability has been based on observation of the early spring growth which by virtue of its fresh, green appearance would readily indicate that the burning was a stimulation in contrast to where the old grass is allowed to remain unburned. In this latter case, the spring growth of the bluegrass is partly covered by the old grass and is, therefore, not very visible and even though much more rapid and productive, it is not until the growth of this grass is sufficient to hide the old grass that the comparative rate of growth is appreciated. In view of the widespread acceptance of the practice of spring burning meadows, experiments in various states to determine the desirability of this common practice, would prove exceedingly interesting.

SOME DETERMINATIONS OF PLAT VARIABILITY[1]

C. K. McClelland[2]

I. PRELIMINARY TESTS OF LAND FOR EXPERIMENTAL USES

Early in the spring of 1925, the Arkansas Experiment Station purchased an adjoining 100 acres for experimental purposes. The part that was assigned to the Agronomy Department was laid off in sections 138 feet by 800 feet. The actual experimental area was to be twenty-four 1/10-acre plats 33 feet by 132 feet, without alleys. No experiments were planned for several of these sections and they were cropped in oats and corn to determine variability of the soil. Fulghum oats and Paymaster corn (our better varieties) were used in this test.

No fertilizers were used on oats, but the corn land had an application of stockyard manure. At harvest time the oat sections were staked off into 1/10-acre plats, the ends squared, and the oats harvested by plats. The yields are shown in Table 1. The corn was harvested by rows or one-half rows, each weighed separately. The results from one section were combined in various ways to study the effect of size and shape of plat on experimental error. The yields by one-half rows are given in Table 2 and by 1/10 acres (adjacent and distributed rows) in Table 1. Table 1 also gives the mean yield of the

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[1] Contribution from the Department of Agronomy, Arkansas Agricultural Experiment Station, Fayetteville, Ark. Research Paper No. 39, Journal Series, University of Arkansas. Received for publication May 26, 1926.

[2] Assistant Agronomist.

24 plats on each section, the standard deviation, the probable error of a single plat, and this error in percentage of the mean.

It will be noted that this land shows great uniformity as determined by this single test. The percentage of variability ranged only from 6.06 to 8.5 in the four sections. Evidently such land is safe to use for experimental purposes. Another section, on a different part of the area purchased, did not give such good results, the error amounting to 17.1%. On this land another trial will be made before using it for test work.

TABLE 1.— *Tests determining uniformity of soil for experimental work.*[a]

Plat No.	Section 39	Section 40	Section 41 (Rows adjacent)	Section 41 (Rows distributed)	Section 42
	Corn	Oats	Corn	Corn	Oats
1	35.0	26.8	29.8	3.67	31.6
2	32.9	27.3	25.6	3.82	36.6
3	45.1	33.2	28.6	3.54	38.4
4	43.5	33.2	32.7	3.72	44.0
5	46.0	37.8	34.5	3.54	42.5
6	44.4	39.7	37.4	3.51	47.3
7	42.3	39.7	37.7	3.45	49.6
8	44.6	43.2	37.1	3.48	48.7
9	42.8	38.6	36.1	3.55	48.5
10	43.7	42.6	39.1	3.47	44.2
11	48.3	43.1	40.1	3.50	44.8
12	46.5	39.5	38.3	3.42	46.5
13	46.4	42.3	34.0	3.40	46.5
14	43.6	42.6	38.4	3.41	46.5
15	42.1	42.8	39.9	3.51	42.2
16	37.9	37.5	42.9	3.33	43.4
17	40.6	37.2	42.7	3.63	41.9
18	44.8	40.8	38.0	3.52	44.8
19	44.5	41.9	34.4	3.60	42.3
20	43.3	42.8	36.4	3.57	44.0
21	39.6	36.6	33.6	3.62	39.5
22	41.5	39.1	32.1	3.55	38.3
23	35.8	40.0	29.1	3.60	36.4
24	38.6	29.3	31.6	3.56	27.9
Mean . . .	42.2	38.2	35.4	3.54	42.4
St. Dev. . .	3.79	4.81	4.36	0.112	5.25
E_s	2.56	3.25	2.94	0.076	3.54
E_s in percentage of Mean	6.06	8.50	8.30	2.14	8.36

[a] Area of plats 1/10 acre—corn plats harvested by single row, nine adjacent rows making 1/10 acre.

Where distributed—Rows 1, 25, 49, 73, 97, 121, 145, 169, 193 used in first plat; 2, 26, 50, 74, 98, etc., in second plat, and so on.

TABLE 2.—*Yields of one-half rows of corn, 1925.*[a]

½ row = 44″ x 66′ = 1/180 acre.

East	West	East	West	East	West	East	West
12.0	11.6	14.2	13.0	11.4	11.4	13.8	12.0
15.0	13.8	14.0	15.4	11.6	13.2	13.8	12.4
13.0	10.4	16.0	14.8	12.0	15.0	13.0	13.6
12.4	13.2	16.0	16.0	11.6	12.4	12.0	12.8
12.6	10.0	13.4	14.6	14.0	17.0	14.0	15.0
9.8	11.2	15.4	14.4	11.4	15.0	13.2	14.2
11.4	10.0	15.0	15.4	14.4	14.0	15.0	15.8
11.2	10.0	16.6	13.4	12.6	16.6	15.0	13.8
12.4	9.0	14.6	15.2	14.2	13.2	14.6	13.2
10.0	9.6	15.6	15.0	15.0	13.2	14.6	12.0
11.0	8.8	14.6	13.0	16.0	16.4	15.0	12.2
12.4	7.0	14.4	15.0	14.6	14.8	14.0	14.2
10.0	8.2	12.0	13.2	12.0	17.4	16.2	14.0
10.4	8.2	15.2	15.0	15.0	17.4	13.4	12.8
12.2	6.8	15.0	12.0	14.4	17.0	15.0	13.8
11.0	8.4	17.4	12.2	14.0	15.0	14.8	12.4
13.8	11.6	16.0	14.4	16.0	15.4	13.4	12.0
11.2	8.4	15.0	13.4	16.2	15.0	12.2	12.4
13.0	7.6	14.0	13.8	17.0	14.2	9.6	13.0
13.2	8.2	14.0	14.8	15.4	12.8	13.2	12.8
14.6	7.0	13.6	15.0	14.0	15.0	14.6	13.0
14.0	7.8	14.2	13.2	16.0	14.0	14.2	14.4
13.4	11.4	14.0	14.4	17.4	14.0	13.0	15.2
11.6	9.4	12.2	15.0	17.0	13.6	11.0	14.2
12.6	12.4	13.4	14.0	20.6	16.2	14.0	14.6
10.0	12.6	14.8	14.0	15.6	13.6	12.4	16.0
11.0	10.4	13.6	15.0	13.4	14.8	9.4	14.6
14.0	11.0	13.2	15.6	17.8	15.0	11.0	14.0
11.8	12.6	14.0	15.0	21.0	14.4	12.6	15.2
12.6	12.2	15.0	16.2	20.0	16.0	10.0	13.8
12.4	11.0	14.0	17.0	20.6	14.4	11.0	11.8
12.4	13.2	15.8	15.0	19.0	18.4	11.0	11.0
13.4	14.2	16.0	13.8	15.4	17.6	12.4	11.2
13.8	11.2	15.2	18.0	18.2	15.4	11.8	13.6
14.0	13.4	16.6	14.6	18.8	17.6	10.8	12.4
12.0	13.6	15.6	16.6	19.2	15.0	11.2	10.6
13.0	12.2	15.0	15.4	20.8	16.4	10.6	11.0
13.6	14.6	15.0	16.4	21.0	17.2	10.4	11.0
13.6	12.4	15.2	14.8	17.0	12.4	12.0	10.6
11.4	13.4	15.0	15.4	18.0	16.0	10.0	11.0
14.4	12.6	13.6	15.0	15.2	14.0	10.2	11.0
14.4	13.6	14.0	16.8	17.0	14.0	12.4	13.0
13.0	12.2	18.0	17.0	15.2	15.4	12.0	11.4
14.2	15.0	17.0	14.8	16.2	14.0	12.4	13.0
14.0	13.8	14.4	13.8	15.0	15.0	11.8	13.0

[a] Numbers of rows not given. From North to South, record reads down first double column, then second, third, and fourth in succession.

TABLE 2.—*Continued.*

East	West	East	West	East	West	East	West
13.0	13.6	17.0	16.0	14.6	14.0	11.0	12.0
14.0	15.6	14.4	15.0	15.0	13.6	13.4	13.0
15.6	15.4	15.4	15.4	11.4	14.6	11.6	15.2
15.0	15.6	15.4	14.2	15.6	15.0	10.6	11.6
16.0	17.0	15.8	14.0	15.6	14.0	10.6	12.0
11.6	13.2	16.4	12.6	16.6	14.6	12.2	14.4
15.2	14.0	15.4	15.0	15.6	15.6	14.0	10.0
14.8	1.40	14.4	13.4	14.2	12.4	11.4	11.0
14.0	14.2	12.4	13.4	14.2	12.8	8.2	9.4
13.8	12.4	12.4	15.4	14.6	13.0		

TABLE 3.- *The effect of size and shape of plat on error in field plats (with corn).*

Size of plats	Number of plats	Number of rows 44" apart	Length of rows in feet	Error %
1/180 acre	432	1	66	11.2
1/90 acre	216	2	66	10.3
1/90 acre	216	1	132	9.7
1/60 acre	144	3	66	9.7
1/45 acre	108	4	66	9.7
1/45 acre	108	2	132	9.0
1/36 acre	86	5	66	9.5
1/30 acre	72	6	66	9.4
1/30 acre	72	3	132	8.6
1/30 acre	72	3[a]	132	3.55
1/20 acre	48	9	66	8.9
1/18 acre	42	10	66	9.0
1/18 acre	43	5	132	9.6
1/15 acre	36	12	66	8.8
1/15 acre	36	6	132	8.6
1/12 acre	28	15	66	8.6
1/10 acre	24	18	66	8.4
1/10 acre	24	9	132	8.3
1/10 acre	24	9[a]	132	2.1
1/5 acre	12	36	66	6.8
1/5 acre	12	18	132	7.4
1/2 acre	4	90	66	6.95
1/2 acre	4	45	132	6.2

[a] Rows distributed— all other data from adjacent rows.

II. EFFECT OF SIZE AND SHAPE OF PLAT AND DISTRIBUTION OF CORN ROWS ON EXPERIMENTAL ERROR

Table 3 shows the errors as found by different combinations of rows making varying areas and shapes. The rows were 44 inches apart by 132 feet long and many combinations were possible.

The results show a gradual reduction of error with the increase in size of plat and also a slightly lower error for long narrow plats than for short wide plats of equal area. Most investigators have shown no reduction of consequence by passing below 1/20 to 1/40 acre in size, but these results show reduction of nearly 30% in going from 1/30 to ½ acre. With few exceptions, other results have shown a reduction in error in long narrow plats, in agreement with these. By distributing the rows the error for 1/30 acre is reduced from 8.6% to 3.55% and for 1/10 acre is reduced from 8.3% to about 2%, showing a great advantage in such distribution.

REPORT OF COMMITTEE TO FORMULATE A COOPERATIVE PROGRAM OF CORN IMPROVEMENT UNDER THE PURNELL ACT[1]

INTRODUCTION

The committee on a cooperative program for corn improvement under the Purnell Act met in Lansing, Michigan, July 8, 9, and 10, 1925. At this time they drew up a preliminary report containing a brief statement of some of the problems that should be covered. Copies of this report were mailed to Dr. E. W. Allen and to the directors of the 12 states involved with the request that criticisms or suggestions be sent to the committee so that they might have the benefits of these before preparing their final report.

The committee met again at Chicago, Illinois, November 16 and 17, 1925. Prior to this meeting replies were received from most of the stations. The concensus of opinion apparently was that the program was broad but that it should be in somewhat greater detail. The idea of those desiring most detail appeared to be that this would permit the corn investigations at the different stations to be coordinated so as to avoid duplication, supplement each other, or be comparable where it seemed desirable to carry on the same type of experiment under different environments. The directors at most of the stations seemed to agree with the majority of the committee that no program which could be drawn up in advance could cover all points in any event and that coordination and cooperation could be achieved better by having the committee continue to function in an advisory capacity.

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[1] Committee: W. L. Burlison, Illinois, *Chairman;* L. C. Burnett, Iowa; H. K. Hayes, Minnesota; G. N. Hoffer, Indiana; T. A. Kiesselbach, Nebraska; S. C. Salmon, Kansas; L. J. Stadler, Missouri; L. R. Waldron, North Dakota; and F. D. Richey, U. S. Dept. of Agriculture, *Secretary.* Report received for publication from the Secretary of the Committee, June 26, 1926.

In preparing its final report the committee has been actuated by both of these points of view, as well as by the following facts: (1) The production of improved varieties of corn for different localities inherently is a local problem. (2) Many of the general problems must be solved under several different environments if the underlying principles are to be determined. (3) Investigations of the more fundamental problems are undertaken by those stations that are best equipped to pursue such studies. (4) There already is a great deal of personal cooperation among the investigators at the different stations and in the U. S. Department of Agriculture. Consequently, there seems to be little danger of undesirable duplication and the coordination of results along the same line can be achieved best by providing for annual meetings of the leaders in these investigations and, possibly, by having the committee function in an advisory capacity.

With this in mind the program has been outlined rather as a series of problems which require attention. After the statement of each problem is a brief discussion, with a final presentation of some general considerations, including the possibilities of cooperation and coordination.

As evidence of the present status of corn improvement, the committee wishes to submit as an inherent part of its report the papers presented at the symposium on this subject held at the meeting of the American Society of Agronomy in Chicago, November 17, 1925. These papers are to be published in an early number of the JOURNAL of the Society and copies will be sent to the directors in the states concerned when issued.

PROBLEMS

A. Production of improved sorts for different localities for such characters as high yielding capacity, resistance to various diseases and insects, quality of product, and adaptation to specific environmental conditions.

Discussion.—This states the ultimate object of the improvement program as a whole. It is given as a separate item because of its importance and because it is entirely possible to produce better sorts empirically while obtaining solutions of some of the underlying problems necessary to an intelligent effort to obtain maximum yields.

B. Determination of the better methods for obtaining selfed lines.

1. Determination of characters associated with desirable lines.
   a. Resistance to drought.
   b. Resistance to cold.
   c. Resistance to diseases.

d. Resistance to insects.
e. Indexes of productiveness.
f. Value in combinations.

Discussion.—Little is known at the present time as to what constitutes a desirable selfed line. In localities where drought, cold, insects, or disease is the factor limiting corn production, resistance to such a condition may be the most important consideration in selecting selfed lines. In the absence of such dominating condition, however, the problem is more difficult. If progress is to be certain it is not enough to discard lines with obvious defects. The relation of characters that may be used as indexes of positive value, such as size of ear, size of seed, strength of stalk, tillering habits, character of root system, seedling characters, etc., also must be found. Finally, the relation must be determined between the desirability of the selfed lines and their value in hybrids.

2. Comparison of different sources for obtaining selfed lines and studies of the relation between the intensity of selection and the probability of obtaining desirable lines.

a. One variety with several varieties.
b. Adapted with unadapted varieties.
c. Varietal crosses with varieties.
d. Recombined selfed lines with open-fertilized corn.
e. Extensive with intensive selection.

Discussion.—Obtaining desirable selfed lines primarily is a problem of selection. The limiting conditions are the area and labor available for growing the material and making the selections. Are the chances of obtaining desirable lines better if several varieties are used rather than one? Is it important to use only adapted varieties? May varietal crosses furnish a better foundation stock than existing varieties? Will combinations of the best selfed lines already isolated be a better basis for obtaining further progress than new varietal selections? A similar problem is the relative efficacy of extensive and intensive selection. Is it preferable to select among many unrelated lines or among fewer original lines each represented by several sub-lines? All of these questions must be answered before the best procedure in a corn improvement program is definitely known.

3. Studies of the degree of homozygosity desirable before combining.

Discussion.—The importance of self-fertilization in corn breeding is due to the rapid fixation, by this method, of definite entities from among which to select. How long must self-fertilization be practiced before reasonably definite entities can be obtained? Is it undesirable to carry self-fertilization farther than is necessary to obtain homozygosity for certain characters?

C. Determination of the better methods of utilizing selfed lines.

1. The possibility of obtaining selfed lines which are of superior yielding ability in themselves.

2. The relative value of:
   - a. Single crosses.
   - b. Double crosses.
   - c. Synthesized varieties.

Discussion.—Up to the present time self-fertilization of corn has led to some reduction in vigor. The possibility of obtaining a selfed line that is high yielding in itself should not be overlooked. More definite promise, however, lies in the use of single crosses, double crosses, or synthesized varieties.

The method of double-crossing, i. e., crossing two F_1 crosses, has been suggested to obviate the high cost and poor quality of F_1 crossed seed, due to the weakened condition of the selfed plants on which the F_1 seed was produced. More intensive selection in recent years has indicated that selfed lines can be obtained that will be sufficiently productive so that a good quality of single-crossed seed can be produced at reasonable cost. There remains the possibility that crosses involving four or more lines may be more productive under field conditions, either because of their greater variabilty or for some other reason.

The utilization of single or double crosses requires that the crossed seed be produced each year, involving expense and difficulties of seed production and distribution. Productive synthesized varieties, consisting of a mixture of a considerable number of selfed lines which are good in all combinations, would obviate these difficulties. The development of such varieties also is a promising method for achieving rapid progress where resistance to insects or disease or some specific quality of product is the principal improvement sought.

D. Development of methods for comparing improved sorts.

Discussion.—Nothing will do more harm to the corn improvement program than the exploitation of seed for which extravagant claims are made. No seed should go out from the experiment station that has not been found more productive than the best standard varieties for the locality in question. The development of methods or machinery for making the necessary comparisons, where not already available, should be an important part of the corn improvement program.

E. Development of methods for distributing and controlling seed of improved sorts on the farms of the corn belt.

Discussion.—The use of synthesized varieties which can be grown year after year will involve no more difficulties than the inspection and certification of seed of corn varieties or of small grains. Relatively few farmers are in a position to take care of the necessary technicalities involved in producing crossed seed each year. Such F_1 hybrid seed therefore will have to be produced largely by centralized agencies and such agencies must be developed. Seedsmen well may have a place in producing and selling crossed seed. If they obtain their stocks from the experiment stations, regulations for control must be evolved, so that the prices charged will be reasonable and the seed sold will be as represented. This applies either to commercial seedsmen or to farmers who may specialize in the production of crossed seed.

Other important possibilities for growing and distributing crossed seed lie in the cooperation of groups of farmers either independently or through their county agents. As rapidly as crosses more productive than the best local varieties are available, efforts should be made to work out the best methods of cooperative seed production.

F. Studies of the physiology of corn, together with studies of correlated morphologic and histologic characters in health and in disease. The importance of using material of known hereditary constitution, such as selfed lines and recombinations, should be recognized.

1. Water economy.
2. Absorption.
3. Metabolism.
4. Nutritive requirements
5. Toxic phenomena.
6. Temperature relations.
7. Chlorophyl variations.

Discussion.—One working with self-fertilized lines of corn is immediately confronted with striking differences in behavior that must have their origin in the functioning of the plants. The fundamental relations between the plant and its environment must be understood if the development of productive strains for specific conditions is ever to be more than empirical or if maximum yields are to be hoped for.

The relation of water economy and temperature requirements to breeding for drought and cold resistance is self evident. Recent researches, in which the variation in different selfed lines with regard to metabolism during germination at different temperatures and the relation of this to susceptibility to *Gibberella saubinetii*, have been shown, have permitted a scientific attack on breeding for resistance to this organism. Studies on the relative use of mineral nutrients, with their demonstration of the vast differences in nutritive requirements that exist among selfed lines, also open an important field of investigation in the possibility of developing productive strains for specific soil conditions.

G. Detailed genetic and cytologic studies with corn.

1. Studies of the mode of inheritance of characters in corn and their factor relations.

2. Determination of the degree of genetic stability in corn—the frequency of gene mutation and of aberrant chromosome behavior.

3. Studies of the chromosomes in corn and related plants.

Discussion.—Modern methods of corn breeding have developed as a result of advances in fundamental genetics. Corn is a desirable plant in which to make studies in pure genetics and such studies should be of material aid in developing methods of breeding.

The mode of inheritance of miscellaneous simple characters and the linkage relations of the factors involved should be determined. Genetic studies should be accompanied by intensive cytologic investigations. These will lead to an understanding of normal and aberrant inheritance in corn and provide a chromosome map of corn, the necessary "working tools" for investigating the mode of inheritance of more complicated less obvious characters associated with the functioning of the corn plant.

GENERAL CONSIDERATIONS

As noted previously, there is little opportunity for specific formal interstate cooperation in attacking many of these problems. A few of the problems are well adapted to such cooperative attack, and many of them are suited to joint attack by different divisions within the institutions. The coordination of the entire program obviously will be benefited by the close personal cooperation of the individual investigators. The rather free interchange of ideas and material that already exists among the workers at the different stations avoids unnecessary duplication. This has come about naturally and therefore is of the most desirable kind. Coordination also has been aided materially by the fact of cooperation between the states adopting corn improvement as a regional problem and the Bureau of Plant Industry, U. S. Department of Agriculture. This has permitted far more contacts among the investigators than otherwise would have been possible and the resulting spirit of cooperation has been of much value.

The committee feels that everything possible should be done to promote this personal cooperation, as this appears to be the best method of coordinating the program as a whole. With this in mind they recommend strongly that travel necessary to an annual conference of the workers interested be recognized as an integral part of the program and that specific provision for such travel be budgeted out of Purnell funds.

At such meetings, a report on the results of the season's investigations should be presented and discussed. Contemplated new research also could be outlined. This would provide opportunity for voluntary cooperation and coordination. The interchange of ideas as to the best methods, etc., also would be stimulating and highly beneficial.

It is recommended further that the present committee continue to function until the first conference is held in 1926. That conference should elect an executive committee of not more than five members to arrange for future conferences and to act in an advisory capacity, when requested, in coordinating the details of the corn improvement programs in the different states and the U. S. Department of Agriculture. The members of this committee should serve for different lengths of time, so as to provide continuity of action.

AGRONOMIC AFFAIRS

SUMMER MEETING OF THE CORN BELT SECTION

The annual summer meeting of the Corn Belt Section of the American Society of Agronomy was held at University Farm, St. Paul, July 15 to 17, inclusive. The American Society of Plant Physiologists was in session also at the same time and place and participated in the sessions. The attendance varied from 60 to 80 at the various sessions, with the following states represented: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin, and the United States Department of Agriculture.

An informal program of inspection and discussion of the investigational work in plant genetics, farm crops, and soils was provided. The division of plant pathology assisted with the demonstrations of breeding for disease resistance.

At the business session it was voted to accept the invitation of Ohio to hold the next summer meeting at the Ohio agricultural experiment station and college of agriculture.

THE PROGRAM

Thursday, July 15, Morning Session

Room 5, Administration Building, University of Minnesota

Call to order and announcements, Professor Andrew Boss, Chairman, Corn Belt Section, American Society of Agronomy.

Welcome and Address, W. C. Coffey, Dean and Director, Minnesota Agricultural Experiment Station.

Agronomic Achievements and Aims at Minnesota, Andrew Boss, Vice-Director, Minnesota Agricultural Experiment Station.

Afternoon Session

Field Trip—Plant Nursery and Fields, Small Grain Investigations.

1. Small Grain Improvement.
    a. Plan of Work and Outline of Investigations, H. K. Hayes.

- b. Genetic Work with Barley, F. J. Stevenson.
- c. Breeding Hardy Winter Wheats, O. S. Aamodt.
- d. Self-Fertilization Studies with Rye, H. E. Brewbaker.

It was pointed out that the purpose of the investigations with oats at the Minnesota agricultural experiment station is to obtain a high yielding variety which is resistant to smut and to stem rust. Many F_5 lines of a cross between Minnesota x White Russian and Black Mesdag are immune to smut and highly resistant to rust.

Three varieties of barley— Velvet, Glabron, and Comfort—have been obtained from a cross between a smooth-awned variety and Manchuria. These are smooth-awned varieties of the Manchuria type and are quite resistant to the spot blotch and root rot disease caused by *Helminthosporium sativum.*

The genetic studies have for their object the determination of linkage in barley. The four cultivated species of barley have seven pairs of chromosomes and it should be possible, therefore, to demonstrate seven linkage groups. This work is being conducted in cooperation with the experiment stations of Oklahoma, Colorado, and Svalof, Sweden. Breeding hardy winter wheats with improved quality and disease resistance is one of the main wheat breeding problems. Segregation of hardy and non-hardy strains of wheat from crosses between spring and winter varieties was clearly demonstrated.

Investigations in rye breeding through selection in self-fertilized lines have been continued for six years. A high degree of self-sterility and decreased vigor characterizes most of the inbred lines, but some strains appear highly self-fertile and a few after several years selfing appear normal in vigor.

2. Crop Studies with Small Grains.
   - a. Scope of Investigations with Grain Crops, A. C. Arny.
   - b. Variety Tests, F. H. Steinmetz.
   - c. Flax-Wheat Mixture, J. H. Lefforge.
   - d. Crop Succession and Effects, F. L. Higgins.

A comprehensive plan for variety testing and other crop work has been developed for the state. Under this plan all workers interested in crop work at University Farm and the branch stations cooperate to find the best varieties for the state as a whole or any part of the state having conditions that differ from other parts.

The yields secured at all locations are compiled at University Farm and a copy furnished to interested cooperaters. At a meeting, generally held in January, the records are considered and the list of recommended varieties for the year is made out. All promising varieties developed outside the state are tested along with those developed by the plant breeders in the state and the ones proving best suited to conditions are put on the recommended list. In examining the oat varieties the stiffness of the straw of Gopher and the promising appearance of several new rust-resistant, medium-maturing selections was noted. The comparative freedom from smut of the variety Markton was outstanding. Among the spring wheat varieties the appearance of the varieties Ceres and Marquillo checked up with their favorable performance records.

There was less lodging in the variety Glabron among the barley varieties than any of the others except the Minsturdi. Glabron has yielded higher than any of the other varieties over a three-year period.

In studying the flax-wheat and flax-oat combination crops, it was pointed out that flax sown at the rate of 42 pounds per acre together with wheat at 45 pounds per acre have yielded 10.78% higher than the same crops grown alone at the usual rates of seeding.

Friday, July 16, Morning Session

1. Field Trip—Corn, Forage Crops, and Crop Rotation Investigations.
   a. Crop Rotations, A. C. Arny.
   b. Alfalfa—Time of Cutting, A. C. Arny.
   c. Alfalfa Varieties, F. L. Higgins.

Wheat and corn grown in a five-year rotation, including one year each of hay and pasture and one year of oats where 10 tons of manure is applied preceding the corn, have yielded 23.5% and 13.2%, respectively, during the last five-year period higher than in a three-year rotation of wheat and corn where all of the crops have been removed and no manure applied. This work was started in 1899.

On another rotation field started in 1909, where manure is applied at the same rate, 2 tons per acre per year, in all systems of cropping, during the first six years crops in rotations including a legume yielded higher than the same crops grown continuously. In rotation wheat, oats, and corn yielded 44.9%, 17.6%, and 15.8% higher, respectively, than the same crops grown continuously. For the first ten-year period the increases in yield in percentages have been as follows: Wheat, 28.16; oats, 19.08; and corn, 22.02.

Rotations including legumes show increases in yields even when barnyard manure is available in fair amounts.

At University Farm, Waseca, Morris, and Crookston, all of the variegated flowered alfalfa varieties have been about equally hardy and productive. Kansas- and Nebraska-grown seed of common alfalfa can not be relied on to pass through any winter after the first. Plantings made from seed from the Argentine winter killed almost completely the second year from seeding.

At Grand Rapids, Grimm and Baltic are the only satisfactory varieties of alfalfa. Cossack, Hardigan, and Ontario Variegated winter killed badly.

Over a period of years, cutting alfalfa at the tenth bloom stage with the last cutting removed by September 1 to 10, so that a growth of from 4 to 6 inches for winter protection was made before the end of the growing season, has been satisfactory both from the standpoint of maintaining stands and producing yields of hay. Both winter covering and root reserves have been found of importance in maintaining stands.

2. Corn Genetics and Plant Breeding Investigations, H. K. Hayes.
   a. Genetic Investigations, H. E. Brewbaker.
   b. Inheritance of Smut Resistance, Forrest Immer.
   c. F_1 Crosses of Better Selfed Strains, G. Nilsson-Leissner.

Corn breeding investigations at Minnesota aim at the production of improved varieties through selection in self-fertilized lines. Inbred stains have been isolated from several of the standard dent, flint and sweet varieties and one pop variety. Sixty-five of the better selfed strains are being studied intensively for resistance to corn smut and some of the root rot diseases. These are also being tested in various combinations as single and double crosses, some of the double crosses giving as high as 30% increase in yielding ability over the original variety. Synthetic varieties have been produced by recombining several selfed lines, all of which originated from the same variety and these are being tested for yields.

Genetic investigations involve the inheritance and linkage study of several characters found in the selfed strains. A linkage study of smut resistance and susceptibility is being conducted with the hope of determining the location of a factor or factors for this character in the already established linkage groups.

Afternoon Session

1. Field Trip—Inspection Sand and Peat Experimental Fields at Coon Creek.
   a. Peat and Sandy Lands—Their Needs, F. J. Alway.
   b. Crop Behavior on Peat Lands, G. H. Nesom.
   c. Soil Amendments, C. O. Rost.
   d. Variety Behavior on Sandy Lands, F. W. McGinnis.

Winter rye and winter wheat have proved much more profitable on sandy lands than spring-sown grains. The higher yields of fall-sown grains is due in part to the favorable conditions for growth as far as moisture is concerned in the fall and spring.

Soybeans and field peas produced low yields on this type of soil.

Corn produced an average yield of 20.40 bushels per acre on a 14% shelled basis as an average for a period of years.

Due to the comparative ease with which a successful stand of alfalfa may be secured on this type of soil and the comparative permanence of the crop after a stand is secured, this crop is taking the place of clover rapidly as a hay crop. On fields where the requisite amounts of lime have been applied, sweet clover may be grown successfully for pasture.

Saturday, July 17, Morning Session

Field Trip—Breeding for Disease Resistance.
   a. Cooperative Investigations in Disease Resistance, H. K. Hayes.
   b. Breeding for Rust Resistance in Wheat, O. S. Aamodt.
   c. Disease Resistance in Flax, A. W. Henry.
   d. Resistance to Root and Stalk Rots in Corn, Paul Peterson.
   e. Resistance to "Spot Blotch" in Barley, F. J. Stevenson.
   f. Resistance to Foot Rots in Small Grains, J. J. Christensen.
   g. Other Plant Pathology Investigations, E. C. Stakman.

The plant breeding and plant pathology departments demonstrated the cooperative work of breeding field crops resistant to disease. Some of the crop diseases are often the limiting factor in production and for this reason the desirability and necessity of obtaining varieties immune or highly resistant to these diseases were emphasized repeatedly. The necessity of taking into consideration in breeding for disease resistance the various physiologic forms of the pathogenes was also stressed.

Afternoon Session

Fruit Breeding Investigations at Fruit Breeding Farm, Zumbra Heights.

The fruit breeding farm is located 20 miles west of Minneapolis and is devoted exclusively to the breeding of horticultural crops. The farm consists of 116 acres fully occupied at present with tree and fruit crops in various stages of development. Professor Brierley acted as chairman for the section meeting and gave a brief review of the work in progress. A large number of new varieties have been developed and distributed for growth by nurserymen and others. A bulletin is in press describing these new varieties. The afternoon was spent in studying the methods employed in plum breeding and in determining winter hardiness of apples. Dr. J. H. Beaumont and A. N. Wilcox presented the technical phases of the work.

ANDREW BOSS, *Chairman.*

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SYMPOSIUM ON "SOIL BACTERIOLOGY—NITRIFICATION STUDIES"

Leader: A. L. WHITING, University of Wisconsin

1. "Nitrates in Soils As Influenced by the Growth of Plants." T. L. Lyon, Cornell University.

2. "Nitrate Accumulation in Soil as Influenced by Tillage and Straw Mulch." W. A. Albrecht, University of Missouri.

3. "Some Important Factors Controlling the Rate of Nitrification of Organic Materials." A. L. Whiting, University of Wisconsin.

4. "Studies on the Nitrification of Ammonium Sulfate in Soil." H. J. Harper and Bryan Boatman, Iowa State College.

5. "The Nitrate Content of Rhode Island Experimental Plats as Influenced by Fertilizers and Crops." John B. Smith, Rhode Island Agricultural Experiment Station.

6. "Ammonia and Nitrate Studies of Lakes near Madison, Wisconsin." E. P. Domogalla, City Biochemist, Madison, Wisc., and E. B. Fred, University of Wisconsin.

1. NITRATES IN SOILS AS INFLUENCED BY THE GROWTH OF PLANTS[1]

T. L. Lyon[2]

Crop plants may influence the nitrate content of a soil when the entire plant is incorporated with the soil or when only the crop residues are so treated. The living plant may also have a direct influence on the accumulation of soil nitrates while the crop is growing.

The effect of green manures and of various crop residues on the accumulation of nitrates in soil has received consideration at the hands of a very considerable number of investigators. In some experiments the plant tissues have increased the nitrate content of the soil as compared with soil not so treated; in other tests the reverse has been the case. Nearly all the experiments reported have shown that legumes grown as green manures produce a higher nitrate content soon after being incorporated with the soil than do non-legumes, unless the latter are treated in this way while very young. In experiments by White (26)[3] in which green manuring plants were incorporated with soil and nitrates determined at intervals of about two months, young wheat and rape plants produced a higher nitrate content throughout a period of nine months than did the same weight of legumes which were more mature.

Several investigations have been conducted in which green manures cut at different stages of growth have been incorporated with soil with the result that more rapid accumulation of nitrates, or better plant growth, was secured from the same plants when used at the early stages of growth than when mature or nearly so. Such results were obtained by White (26), Hutchison and Milligan (6), White (27), Maynard (16), Merkle (17), and Martin (15) and appear to hold at least when equal quantities of the young and old plant tissue are employed.

Experiments with crop residues have been conducted under very various conditions and with many crops. It is hardly practicable to mention them individually. In the main they show that legume residues produce a greater accumulation of nitrates during most of the period when the succeeding crop would use them than do similar treatments with non-legumes. In few instances have determinations of nitrates been continued over a very long period after the green manures or crop residues have begun to decompose. However, Brown and Allison (1) found that the second crop of oats after incorporation of green manures yielded more abundantly following the non-legumes, although the reverse was the case with the first crop. In experiments by Lyon, Bizzell, and Wilson (12) nitrates, during the first few weeks, were greater in amount in soil containing clover residues than in soil containing timothy residues but were finally less in the former soil after six months' incubation and leaching. This was under conditions very favorable for decomposition. The significance of these results will be discussed later.

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[1] Paper read as a part of the symposium on "Soil Bacteriology—Nitrification Studies" at the meeting of the Society held in Chicago, Ill., November 17, 1925.

[2] Professor of Soil Technology, Cornell University, Ithaca, N. Y.

[3] Reference by number is to "Literature Cited," p. 839.

Many experiments have been conducted with straw for the purpose of ascertaining its effect on the accumulation of nitrates. These were often occasioned by the observation that the plowing under of large quantities of straw had a deleterious effect on the yield of crops planted on the straw-treated soil. The injurious effect of straw has been traced by several investigators to the depressing influence it exerts on nitrate accumulation in soil. Among these are Green (4), Wright (29), Stephenson (23), and Murray (18). The first two investigators also tried the effect of substances containing no nitrogen, such as dextrose and cellulose, on nitrate accumulation and found that they had a depressing effect even more pronounced than that of straw.

Is it the ratio of carbon to nitrogen in the plant tissues, or other substances added to soil, that determines the rate at which nitrates will accumulate during a certain period following the incorporation of the material? An experiment was reported by Lyon, Bizzell, and Wilson (13) in which the roots of oats, timothy, maize, clover, and dried blood were each allowed to decompose in soil contained in as many drainage cans. The carbon-nitrogen ratio was widest for the oats and was narrower for each of the other substances in the order named. Enough of each substance was added to furnish 0.6 gram of nitrogen. They were incubated for three months, leached, and nitrates determined in the leachings. The quantities of nitrogen recovered as nitrate was in inverse order to the width of the carbon-nitrogen ratio.

Kelley (8) found that about the same amount of ammonia accumulated from the addition to soil of casein or cottonseed meal or linseed meal, etc., when enough starch was added to bring the combined substances to the same carbon-nitrogen ratio.

The generally accepted explanation for the depressive influence of organic substances high in carbon on nitrate accumulation is that the carbonaceous matter furnishes a source of energy for soil organisms which utilize the nitrogen of nitrates. Hence, the more energy material there is the more nitrates will they consume. Being used for the growth of the organisms the nitrogen remains in the soil largely in the form of organic compounds.

It is held by some investigators that part of the nitrogen is lost by volatilization, but Murray (18) found that the nitrogen originally contained in the soil in the form of nitrates which were decomposed on addition of straw was all recoverable as total nitrogen.

I have cited an experiment (1) in which the first crop of oats following green manures was greater where legumes had grown but the second crop was larger following non-legumes. In another experiment referred to (12) it was found that several times as much nitrate accumulated in clover soil during the first few weeks after turning under as in soil in which timothy had grown, but after being leached at intervals for six months, more nitrates accumulated in the timothy soil during the last period. The question arises, had the rapid formation of nitrates in the clover soil and their removal by growing plants or by leaching finally brought the carbon-nitrogen ratio in both soils to about the same point? Waksman (24) has stated that the tendency for the more highly carbonaceous and more highly nitrogenous materials to reach an equilibrium results in a constant ratio of the carbon and nitrogen in all soils.

When highly carbonaceous organic material is present in soil in undue amount those organisms which utilize such material for energy production compete with green plants for nitrogen and the latter suffer accordingly. The addition of sufficient available nitrogen to supply the requirements of both is the obvious solution. Part, or possibly all, of the nitrogen which is utilized by the organisms is not lost but remains in the soil.

It may also be remarked that the nitrogen which is rendered unavailable to higher plants when an excess of highly carbonaceous matter is present is not confined to the nitrogen of the green manure or crop residues but extends to the nitrogen previously in the soil and to nitrogenous fertilizers.

There is reason to believe that the living plant exerts an effect on the transformation of soil nitrogen in ways other than absorption of nitrogen for growth. It has been noted by several experimenters that there occurs under living plants an apparent disappearance of nitrates which cannot be entirely accounted for by root absorption.

At Grignon it was found by Dehérain (3), as the result of experiments with large lysimeters, that the tanks on which certain crop plants, notably the grasses, were grown furnished less nitrogen in the drainage water, plus the nitrogen in the crop, than did the drainage water alone of the tanks containing unplanted soil. If we are to assume that the nitrogen absorbed by the plants was in the form of nitrate, it would seem that either less nitrate was formed in the planted tanks or that some of the nitrate had disappeared. It is also conceivable that nitrogen may be lost by the plant.

Dehérain explained the phenomenon on the ground that the growing plant by removing moisture from the soil makes the conditions less favorable for nitrification and thus brings about a slower rate of nitrate formation. This theory was tested by Lyon, Bizzell, and Wilson (13) who maintained the same moisture content of the planted and unplanted soil and still found the discrepancy in the nitrate nitrogen in favor of the unplanted soil. This removes the possibility of soil moisture being the determining factor.

Leather (10) in India and Lyon and Bizzell (11) in New York, both working with large lysimeter tanks, observed the same disappearance of nitrate nitrogen from soil on which certain crop plants were growing. The latter investigators suggested that living plants exert a direct influence on the activities of soil organisms.

Russell (20) determined nitrates at the beginning and at the end of the growing season in fallow soil and also where a crop was growing. The nitrogen contained in the crop was not sufficient to account for the nitrate nitrogen that had disappeared. Warington (25) found a somewhat similar disappearance of nitrates under a growing crop. He suggested that the crop may have taken up this nitrogen and afterwards lost it Russell, however, held that the disappearance of nitrate nitrogen in the cropped soil is more properly to be attributed to diminished production, and further, that this is not to be traced to the effect of the crop on the temperature or moisture content of the soil Later, he suggested that growing plants may exert a direct influence on biological activities in soil (21).

The suggestion that nitrogen escapes from the plant has much evidence to support it. There may undoubtedly be a loss of nitrogenous material from the leaves and also from the roots of at least some of the crop plants under certain conditions. This has been shown by the work of Wilfarth, Romer, and Wimmer (28) and by a number of later investigations. While this results in a conversion of nitrate nitrogen into an organic form which is returned to the soil while the plant is living, it is questionable whether it is sufficient to account for the very considerable disappearance of nitrogen which has been observed.

Investigations by Knudson (9) led him to conclude that reducing sugars are excreted by the roots of living plants. Lyon and Wilson (14) found very considerable quantities of organic matter in sterile mineral nutrient solutions in which plants had grown. This organic matter contained only a small proportion of nitrogen. Liberation may be effected by exudation or by the sloughing off of root cells. It was suggested by the latter investigators that the highly carbonaceous organic matter thus given off by plants may act as a source of energy for soil organisms which consume the nitrates and that a disappearance of nitrate nitrogen is caused in this way as well as by absorption by the higher plants.

Hoffman (5) reports the results of experiments conducted by Hammer and Eldridge who drew samples of soil from near the roots of living plants and also at such a distance away as to avoid the presence of roots. Thirty-two tests were made in which infusions of the soil were plated and the number of bacteria counted. On an average two and one-half times as many bacteria were present in the samples taken near the roots as in those at a distance. Hoffman's conclusion from this was that living plants influence the soil bacteria by changing the composition of the soil solution. Joshi (7), working in India, obtained similar results using pots with soil planted and unplanted.

Both of these investigations apparently associate a high bacterial content of the soil with the presence of the roots of living plants. If the roots are liberating material suitable to the development of nitrate-consuming bacteria, a larger number of bacteria might be expected to be present where the roots exist.

There also appears to be a more abundant formation of carbon dioxide in soil in which plants are growing than in unplanted soil. I mention this because carbon dioxide production may be regarded as a measure of decomposition. Neller (19) measured the production of carbon dioxide in soil on which plants were growing and in unplanted soil. He found that much more rapid oxidation takes place in the presence of living plants.

Taken as a whole the evidence seems to favor the idea that growing plants exert a direct influence on the activities of soil organisms and that this influence is exerted through the liberation of organic matter by the roots of living plants.

There is one other possible means by which living plants may cause a disappearance of nitrates in the soil on which they grow. It is well known that oxidizing and reducing substances, probably mainly enzymic, although not entirely so, occur in living plants. Reducing substances were found on the outside of the roots of wheat seedlings by Schreiner and Sullivan (22), and later Lyon and Wilson (14) found reducing substances in nutrient solutions in which maize had grown. No reduction of nitrates by wheat seedlings was found by Davidson (2). There is some evidence that substances liberated by plants are capable of effecting the reduction of nitrates to nitrites, but whether they are an important factor in the disappearance of nitrates in soil is questionable.

The property of living plants to cause a transformation of nitrate nitrogen into other forms is of some practical benefit. It conserves the nitrate nitrogen that the crop does not use and prevents it from being leached from the soil. On the other hand, there is the possibility that there will not be sufficient available nitrogen to supply the crop with all that it needs in the competition with the nitrate-consuming organisms. Fortunately, it seems to be in the later stages of plant growth that these competitors are most active and most crop plants absorb their nitrogen mainly in their early growth. However, there seems to be some evidence that the competition of soil organisms may be, under some conditions, a serious handicap to growing crops. The poor growth of apple trees on sod to which no nitrogen is applied and their vastly better growth when top dressed by a large quantity of nitrate of soda gives some indication of this, for it has been shown that the nitrogen utilized by the grass was not sufficient to account for all of the nitrate nitrogen that disappeared.

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2. NITRATE ACCUMULATION IN SOIL AS INFLUENCED BY TILLAGE AND STRAW MULCH[1]

WILLIAM A. ALBRECHT[2]

Even though plants may use several forms of nitrogen in their nutrition, the nitrate form still stands out as the most important. The amount of nitrate produced in the soil during the season is more essential in determining crop production than the total supply of nitrogen. Numerous soil treatments and conditions influence this nitrogen turnover, or this change from the insoluble nitrogen to the soluble form. Among these, the mechanical treatment, or tillage, has been considered significant. The following study was conducted in the hope of getting some information regarding the influence of tillage, such as plowing and surface cultivation, the influence of the straw mulch, and other factors on the nitrate accumulation in the soil.

SOIL AND TREATMENTS USED

This study deals with one series of 11 plats of a silt loam, classified as a phase of Shelby loam, and 4 plats from a similar series of 10, not far removed, on the same type of soil. The former series was under study for six years, 1920 to 1925, inclusive, and the latter for three years, 1917 to 1919, inclusive. These series included plats with different crops along with different tillage treatments, but only the latter are being considered in this discussion. The treatments and crops on the different plats used are given in Table 1.

The soil of the plats is a shallow silt loam about 7 inches deep underlain by a fairly heavy, more or less impervious, silty clay. The surface has a slope of about 5° and is subject to some washing, but receives little added material due to the sod crops above.

The rainfall of the season was 37.6 inches as a mean for the year, with the distribution giving a significant decrease during the summer months suggesting a droughty condition. This is shown in Fig. 3 giving the nitrates in the undisturbed sod soil and the rainfall distribution by months for the 6 years under study and for 37 years. From these plats it was possible to note the general course of nitrate accumulation under an untilled sod in grass and to study the effects on nitrate accumulation by the general operations of seedbed preparation, including spring plowing and various dates of fall plowing for wheat, by surface cultivation with the ordinary corn cultivator, and by the straw mulch in heavier and lighter applications.

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[1] Paper read as a part of the symposium on "Soil Bacteriology—Nitrification Studies" at the meeting of the Society held in Chicago, Ill., November 17, 1925.

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TABLE 1.—*Treatments in study of influence of tillage and straw mulch on nitrate accumulation.*

Plat No.	Tillage treatment	Crop
	1919–1925, inclusive	
1	None	Grass sod
2	Plowed July 15th[a]	Wheat continually
3	Plowed August 15th	Wheat continually
4	Plowed Sept. 15th	Wheat continually
5	Spring preparation,[b] mulch, 6 tons straw per acre[c]	No crop
6	Spring preparation, mulch, 2 tons straw per acre	No crop
7	Spring preparation, scraped	No crop
8	Spring preparation, cultivated three times	No crop
9	Spring preparation, cultivated 3 times	Corn
10	Spring preparation, scraped	Corn
11	Scraped	Corn
	1917–1919, inclusive	
3	Spring preparation, mulch, 8 tons straw per acre	No crop
4	Spring preparation, scraped	No crop
5	Scraped	No crop
7	Spring preparation, cultivated after each rain	No crop

[a] When soil plowed cloddy it was disked after next rain making such possible. Plats 2, 3, and 4 were worked before seeding wheat in October.

[b] Spring preparation consisted of plowing in April, occasionally in May, together with harrowing to produce a condition similar to a good seedbed.

[c] The mulch was applied after spring preparation and remained until March of the next year when it was removed to allow soils to dry before plowing.

METHODS USED

In the series studied from 1917 to 1919, nitrate determinations were made at intervals of three weeks on the surface 7 inches of soil during the greater part of the three years. On the series during 1921 to 1925 determinations were made every two weeks for almost the entire time, including the winters. Only the surface soil data were taken since data taken on the subsurface showed no significant variation, and since this layer consisting of a silty clay is too impervious to permit much water movement. The samples were taken as 9 to 12 borings per plat of about one seventy-third of an acre area, mixed thoroughly, and triplicate 100-gram samples dried in the oven to determine the moisture. The dried samples were extracted with dilute acid, boiled with alkali to remove the ammonia, and then reduced with De Varda's metal during distillation into standard acid for titration. The nitrates were calculated as pounds of nitrogen per acre of two million pounds of oven-dry soil. The extensive samplings during the six years have given so much data that only the averages for any plat can be given by months or by years. Data of this kind only will be presented.

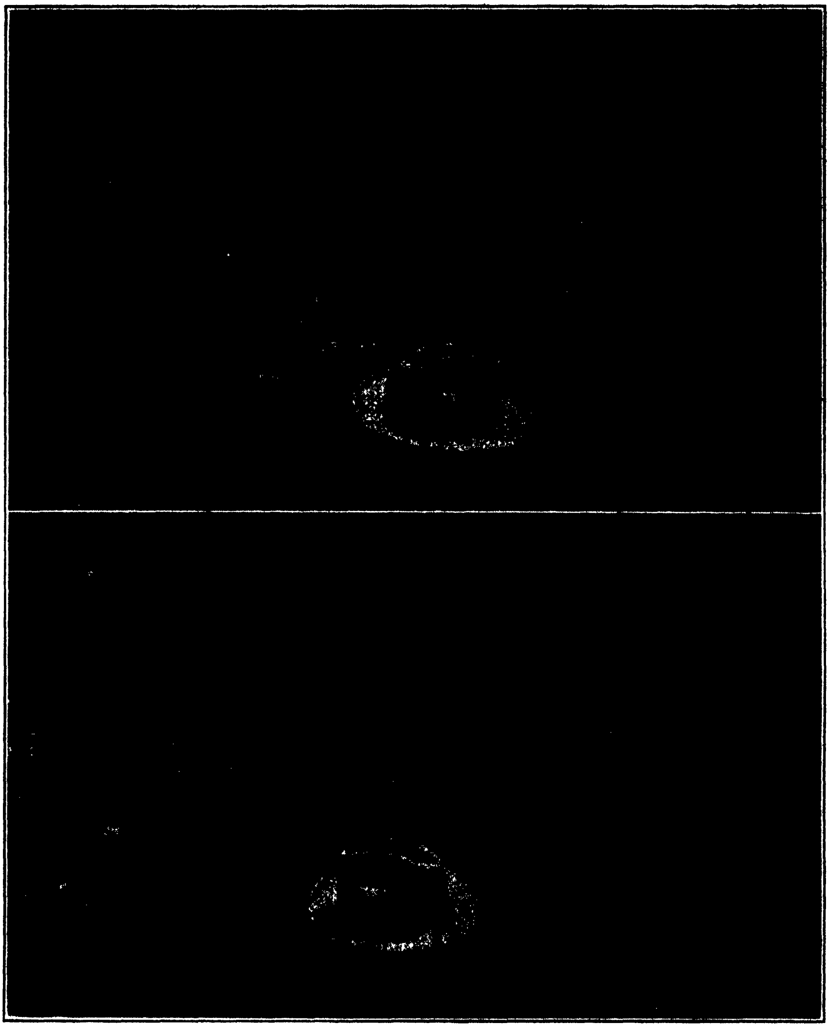

FIG. 1.—Weeds on wheat plats after harvest, as influenced by date of plowing. A, plowed August 15. B, plowed September 15.

EXPERIMENTAL

NITRATE UNDER SOD

The entire area represented by the later series was under cultivation before going into this experiment and sod production was slow the first year. During the remaining time this plat was in a fair sod and was left undisturbed, save for sampling. The nitrate determinations for this sod plat are given as averages by months in Fig. 3.

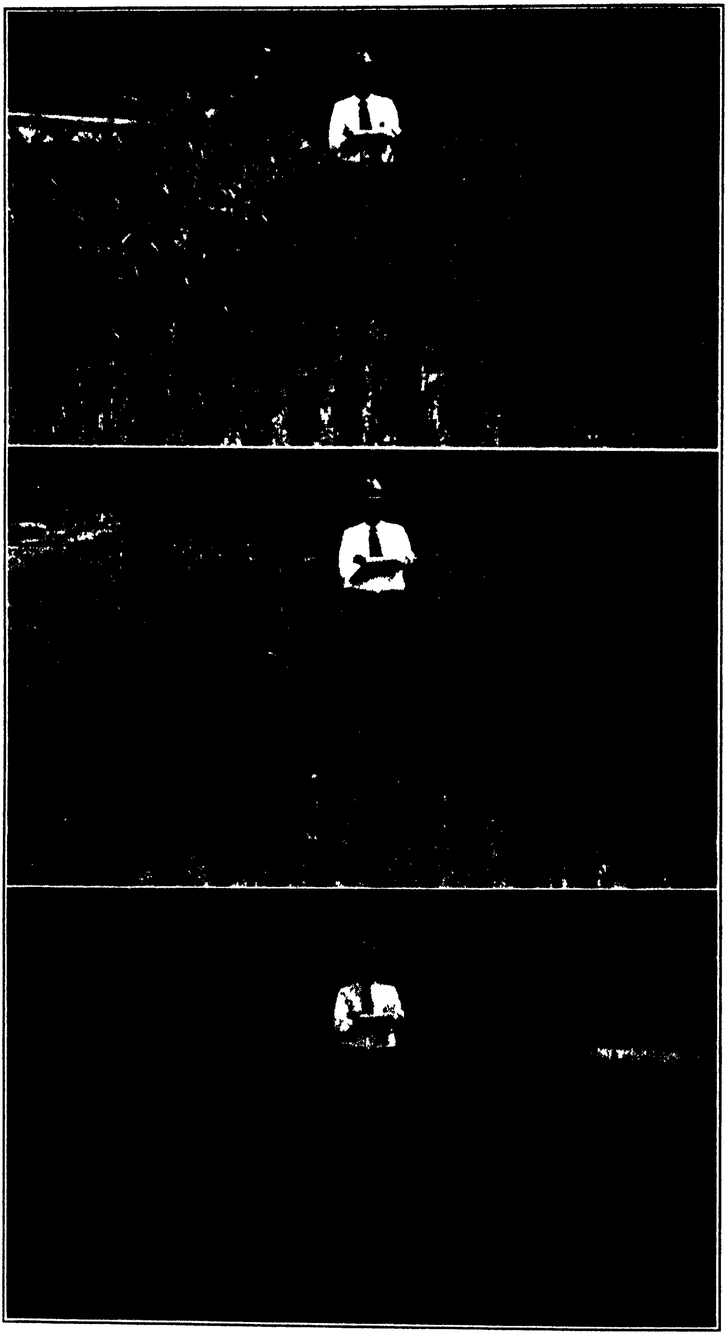

FIG 2 – Wheat growth as influenced by date of plowing
A, plowed July 15 B, plowed August 15 C, plowed September 15

The data for sod show clearly the correlation during the growing period of the nitrate accumulation, in this case, with the moisture supply. The curve of nitrates follows the rainfall curve, as averaged for the longer time, better than that for the six-year period under study. The nitrates show an increase with the increased rain and temperature of the spring until the maximum is reached in May. They then decline until August, probably through removal by grass growth and decreasing moisture until August, when the increased moisture again gives increased nitrates. During all the time, nitrates are distinctly low under sod, since this crop probably keeps them exhausted to this low point. During the last five years, or after the sod was well established, the maximum nitrate accumulation was 17.9 pounds nitrogen per acre which was reached in September, 1923.

INFLUENCE OF SPRING PLOWING

As a means of mixing and aerating soil, the mold board plow is an outstanding implement. For nitrification, which is an oxidative process, plowing should then be a significant operation. That such is the case is shown by the curves in Fig. 4 representing the average monthly nitrate nitrogen in the soil which was unplowed; one which was plowed; and one which was plowed and cultivated. These emphasize the increased nitrate in soil growing corn as a result of aerating the soil through plowing. Similar results were obtained on fallow soils, as shown in Fig. 5 for soils under study three years.

The curves for the unplowed and plowed soils in Fig. 4 show distinct differences in nitrates during the growing season, which averaged 2.16 pounds in favor of the plowed soil from March to August inclusive. The difference for the year as a whole was not so great, however, as was shown by the averages of all the determinations giving 10.29 pounds nitrogen as nitrate for the unplowed soil and 11.95 pounds for the plowed, or a difference for the entire year of about 1.66 pounds. Since the soil samples were taken as far away from the corn plants as possible, it is highly probable that the corn roots reached the point of sampling and removed the nitrates from the plowed soil much earlier in the season than was the case in the unplowed soil. Consequently the data for the latter may be comparably higher which would lessen the difference. This is suggested by the fact that the fallow soils under three years of study, as shown in Fig. 5, give a much wider spread, with an average difference of 6 pounds in favor of the plowed soil, during the months of May to November inclusive.

According to Fig. 4 there is a distinct rise in nitrates in April for the plowed plat while such is not true for the unplowed soil. Since plat 10 was usually plowed during this month one might infer that this operation was responsible for a distinct increase immediately. Such is not the truth, however, since the five-year average for two determinations for a month just after the date of plowing compared with the same average for a month just before the date of plowing is not significantly greater for the plowed than for the unplowed soil. The figures in comparison are 15.02 pounds and 14.44 pounds after and before, respectively, for the plowed soil, and 11.50 pounds and 10.85 pounds for the unplowed soil, giving an increase of 0.58 pound in the plowed and 0 65 pound in the unplowed soil during these two months. This indicates that the operation of plowing on this soil does not give any sudden increase in nitrates, yet serves to bring about conditions giving a general nitrate content in the soil during a long time following, especially through the growing season. Even though this difference becomes almost insignificant during the winter months, the increase during the growing season is large enough to give the plowed soil an annual average nitrate nitrogen content of 11.95 pounds as compared to 10.29 pounds for the unplowed soil.

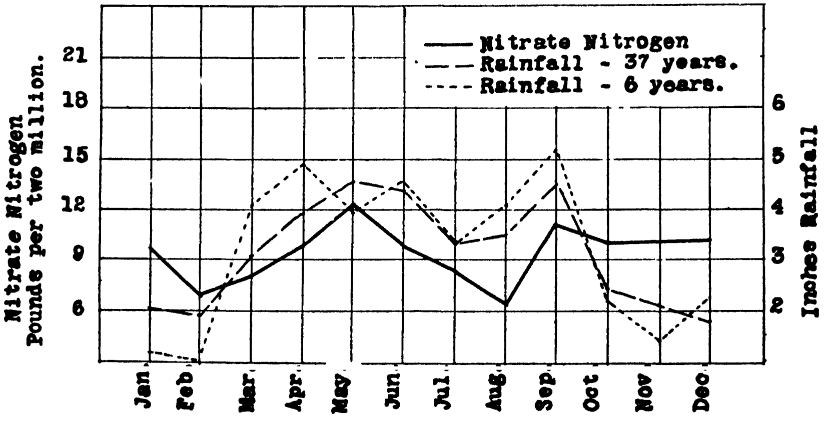

FIG. 3.—Nitrates under soil in sod as correlated with distribution of rainfall.

The yields from these plats are in accord with the differences in nitrates, giving distinctly higher yields for plowing than the differences in nitrate would suggest. Yields are given in Table 2.

INFLUENCE OF FALL PLOWING

Fall plowing also shows some interesting results. Three plats in wheat continually were plowed at varying dates, in preparation for this crop, to note the effect of such on the nitrate accumulations. Plat 2 was plowed for wheat on July 15, Plat 3 on August 15, and Plat 4 on September 15. The data are summarized by averages for

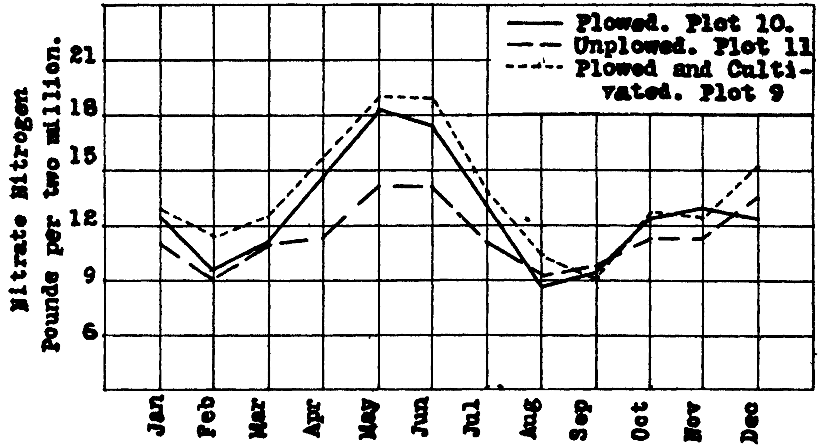

FIG. 4.—Nitrates in soil under corn as influenced by plowing.

the months of the year in graphs in Fig. 6. Since the sampling began in May, 1921, and since these plats did not receive their first treatments until the particular month for plowing, the data are considered beginning with the time of the first plowing.

The outstanding feature of these plats was the increase in nitrates after plowing. Each graph shows a distinct rise for the month in which it was plowed. Plat 2 shows a distinct rise in July; Plat 3 does not rise until August; and Plat 4 falls until August and then

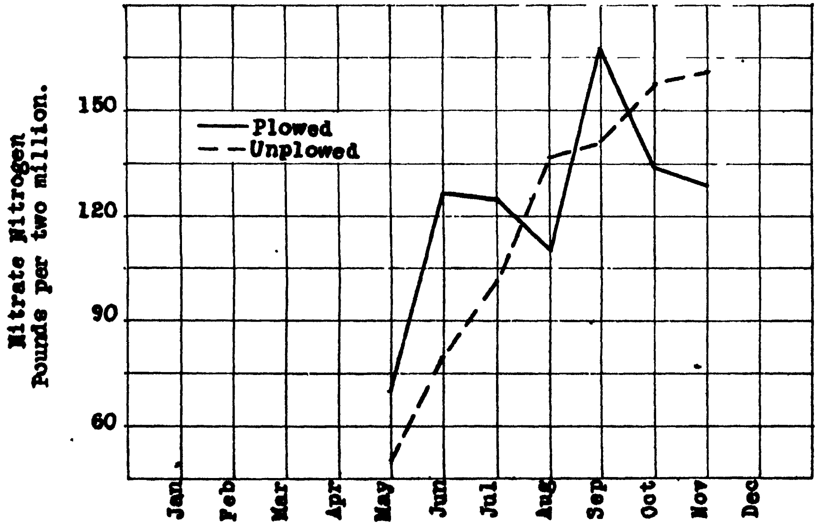

FIG. 5.—Nitrates in fallow soil as influenced by plowing.

TABLE 2.—*Average corn yields (four years) on plowed as compared to unplowed soil.*

Treatment	Bushels
Plowed and prepared	16.33
Not plowed	10.26

rises in September. These increases occur after all plats have come to about the same low level in June, or the month during the latter part of which the wheat was harvested. For the remainder of the season following the time of plowing, and for the early part of the next, the nitrate contents of these plats arrange themselves in decreasing amounts for the later dates of plowing. Plat 3 has an irregularity in the form of a high average for March, reaching 20.98 pounds on account of high nitrates in March, 1921. Severe dry weather during February and March of this year brought crystallized salts to the surface as a distinct bloom. This may have raised the nitrates, but apparently failed to do so in the other two plats. The March average of this plat for the four years following is but 15.7 pounds and would place the graph in more nearly expected order.

That the differences in nitrates were not inherent in the plats at the outset, but are the result of different dates of plowing and effects resulting therefrom, is shown by the nitrate content of these plats before any of them were plowed. Four samplings from May to the middle of July, when the first of the series of plats was plowed, gave an average nitrate content as nitrogen for these plats as follows:

Plat 2	20.6 pounds
Plat 3	21.8 pounds
Plat 4	19.7 pounds

There was no greater variation within these three plats at any one sampling than 3.7 pounds of nitrogen per acre.

The low nitrogen in summer in the later-plowed plats is very probably due to the removal by weed growth. This was regularly heavy on Plat 4 before it was plowed in September. The crop of weeds already present in the wheat stubble at the time of wheat harvest was heavier for the later-plowed plats than for the earlier-plowed plats. The difference in weeds at harvest time between Plats 3 and 4 is shown in Fig. 1. This was the characteristic difference regularly for these plats, while Plat 2 plowed on July 15 seldom had any weeds, since none grew to form seeds to be replanted by the late plowing as was the case in Plat 4.

The heavy weed growth on Plat 4 raises some question regarding the value of a catch or cover crop on this soil. Plat 4 had a catch crop of weeds growing for two months which was turned under in September to be nitrified later. The curves for nitrates fail to show,

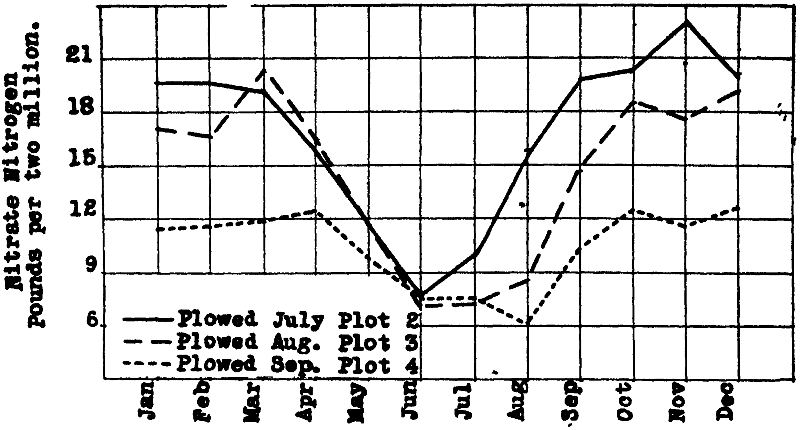

FIG. 6.— Nitrates in soil in wheat as a result of different dates of fall plowing.

however, that this has contributed significantly, since this plat is never the equal in nitrates of the other plats with less, or no, catch crop, except when all three reach their lowest level in June. One might suppose, as is usually done, that the effect of the weeds has been to conserve the nitrogen so that an average figure might not show this effect. If this were true, the differences in nitrate content between the plats should become less as time goes on, to show the effect of this nitrogen conservation in comparison to two months of

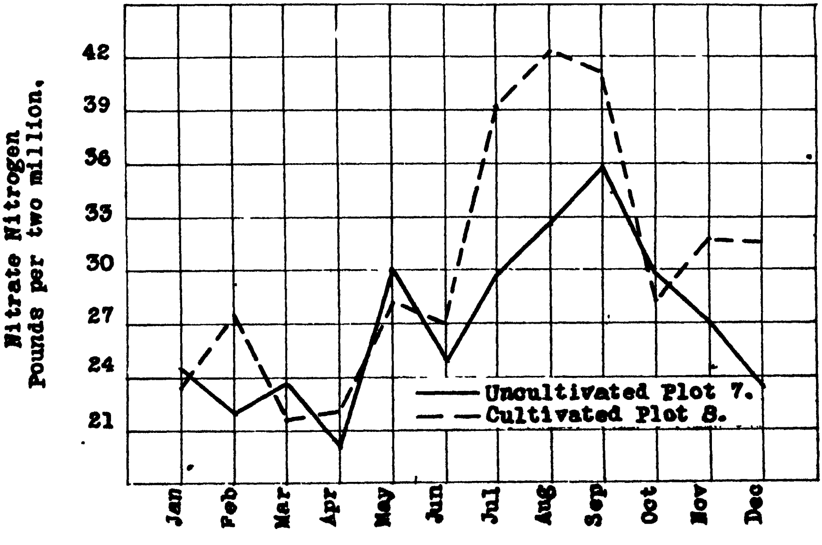

FIG. 7.— Nitrates in fallow soil as influenced by ordinary surface cultivation.

exposure of the bare soil in the early-plowed plat. Contrary to this supposition, however, the difference between the annual averages for nitrates in the early-plowed and the late-plowed plats for the last three years has been 5.5, 5.6, and 5.3 pounds of nitrate nitrogen per acre, respectively. This indicates that regular growth of weeds during the summer has not conserved nitrogen for its conversion into nitrate in later years, and the plat plowed in July to be left bare during the summer goes on producing more nitrates after five years than the plat with a catch crop supposedly saving nitrogen for future conversion.

The crop yields on these plats arrange themselves in the same order as for nitrate content or for time of plowing. Early plowing increased the yield, though this increase was not much greater for July than for August plowing. The data for the yields are given in Table 3 as bushels of grain per acre.

Though the nitrates have been higher regularly in the early-plowed plat, this showed no visible difference either in the fall growth of the wheat or the early spring growth. Later growth showed differences which became pronounced before harvest as shown in Fig. 2 for June, 1923. Since the rainfall curve for this locality suggests no shortage of soil moisture for wheat seeded in late September or early October, the influence of early plowing on wheat yield in this instance seems more probably to have been through increased nitrate production than through moisture conservation.

INFLUENCE OF SURFACE CULTIVATION

That surface cultivation for three times as is ordinarily given corn during the growing season has an influence on nitrate accumulation is evident from Fig. 4 when one compares the graphs for Plats 9 and 10. Plat 9 was prepared in the spring; planted to corn; and cultivated with the regular eight-shovel cultivator three times during the season. Plat 10 received the same spring treatment but was scraped with a hoe to keep down the weeds in place of being cultivated. The nitrate content was regularly higher, though not significantly, in the cultivated plat than in the uncultivated. The average of five years for this difference in nitrates was only 0.63 pounds of nitrogen. The five-year average yields of grain for these two plats were 23.33 and 16.33 bushels, respectively, giving a difference of 7.0 bushels, or much greater than the difference in nitrates would suggest.

TABLE 3.— *Wheat yields in bushels of grain per acre as influenced by date of plowing.*

Treatment	1921	1922	1923	1924	1925	5-year average
Plowed July 15	10.3	13.2	13.7	13.8	13.6	12.9
Plowed Aug. 15.	10.3	14.1	11.3	12.4	15.5	12.5
Plowed Sept. 15.	7.9	11.2	7.2	8.4	6.0	8.1

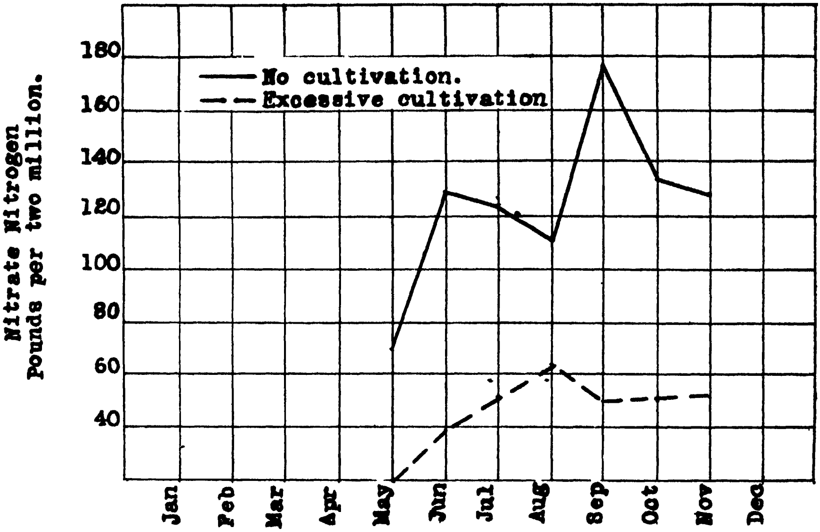

FIG. 8.—Nitrates in fallow soil as influenced by excessive surface cultivation.

Plats 7 and 8 in this series were given the same treatment as Plats 9 and 10 but were uncropped. They also showed significant increases in nitrates as a result of cultivation with the difference becoming most marked after June, the time of the first cultivation. The data are given in Fig 7. Two fallow plats in the series of 1917 to 1919 were similar in treatment, save that cultivation was given after

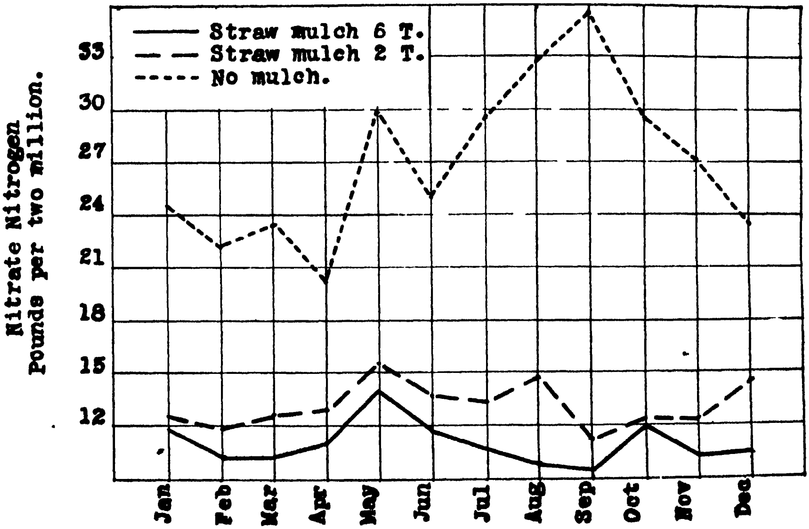

FIG. 9.—Nitrates in soil as influenced by the straw mulch.

every rain. Here the excessive cultivation gave a nitrate accumulation regularly below that in the scraped soil. The data for these two plats are given in Fig. 8.

The data indicate that the regular cultivation served to increase nitrate accumulation but that excessive cultivation served to lessen it. Doubtless the latter treatment kept so much of the surface layer continually dry to the exclusion of nitrate production that sampling to a depth of 7 inches failed to get enough of the regularly moist soil to give significant nitrates.

EFFECTS OF THE STRAW MULCH

That the straw mulch in applications heavy enough to exclude weed growth has a significant depressing effect on nitrate accumulation in soil had previously been reported.[3] In this study two uncropped plats were given applications of 6 tons and 2 tons of wheat straw, respectively. This was left on the soil until early the following spring when it was removed to allow the soil to dry preparatory to spring tillage. The lighter application was not enough to prohibit weed growth, consequently weeds were pulled to keep the plat clean. The nitrate nitrogen found in these plats is given as graphs in Fig. 9 in comparison with that of Plat 7, the uncropped, scraped plat without the straw mulch. These curves show clearly the depressing effect of the mulch in both applications, the heavier being the severer. No single treatment in the entire study showed such significant influence on the nitrate accumulation as the straw mulch. Only in May, after the old mulch had been removed and the soil plowed and remulched, was there any regular and significant rise in nitrates as an average. During single years, significant droughts increased them, but even these increased the total nitrate nitrogen content for the heavily mulched plats to more than 20 pounds per acre but once during the last five years. For over one-half of the determinations, the soluble nitrogen content of this plat was below 10 pounds per acre, or almost as low as that of the plat continually in grass.

The depressing effect of the straw mulch on nitrate accumulation has been shown[4] to be due largely to the increased moisture, which gives a bad physical condition with the exclusion of air to inhibit nitrate accumulation. This effect can be removed or produced in about two months by removing or applying the straw. This suggests the need for caution in selecting the condition under which the straw mulch is to be used.

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[3] ALBRECHT, WM. A. Nitrate accumulations under the straw mulch. *In* Soil Sci., 14:299–305. 1922.

[4] ALBRECHT, WM. A., and UHLAND, R. E. Nitrate accumulations under straw mulch. *In* Soil Sci., 20:253–267. 1925.

SUMMARY

Studies on nitrate accumulations in soils under the straw mulch and various kinds of tillage have shown that these treatments influence the nitrate content of the soil.

The nitrates in an untilled soil, under sod, arranged by months are closely correlated with rainfall distribution of the year.

Spring-plowed plats are regularly higher in nitrates than those unplowed, though this increase may not take place immediately following the plowing. These differences are pronounced during the summer season and almost disappear during the winter.

Fall plowing has a distinct influence on nitrate accumulation as it is done in July or August. Significant nitrate increases follow after plowing for wheat, with greatest increases occurring in the soil plowed in the middle of July.

Weeds growing after wheat and plowed under in the middle of September seem to have no significant effect in raising the nitrate content to the equal of that in the soil without weeds and plowed early.

Ordinary shallow surface cultivation increases the amount of nitrates in the surface soil, but excessive cultivation lessens it

The straw mulch has a decidedly depressing effect on the nitrate accumulation in the soil. This effect may be removed in about two months by removing the straw mulch

3. SOME IMPORTANT FACTORS CONTROLLING THE RATE OF NITRIFICATION OF ORGANIC MATERIALS[1]

A. L. WHITING[2]

INTRODUCTION

The rate of nitrification of organic materials added to or incorporated in soils is of large practical importance in intelligent soil management and efficient crop production. The rate at which nitrates will be produced varies for different materials and is a primary characteristic of the materials and not the soil.

The rapid accumulation of nitrates in a soil is closely related to their production and it is the measure applied for determining the rate. The accumulation should not be confused with the rate of production as they may be influenced by entirely different factors or in a different manner by the same factor. A rain may decrease the accumulation and increase the rate of production. Higher plants, algae, fungi, bacteria, and other forms of soil life may decrease the accumulation and increase the production of nitrates or they may decrease both or increase both. Soil conditions affect the accumulation and the rate of production of nitrates, but in spite of all these considerations the initial speed of nitrification is dependent upon and a characteristic of the materials themselves.

In order to have more definite information as a guide in answering many practical questions on the rate of nitrification of common farm materials and fertilizers, the data concerned with such experiments as occur in the literature and some experiments by the writer and his associates have been used as a basis for the tentative arrangement of these materials in order of their rate of nitrification.

The order must depend upon certain fundamental factors which it is hoped may be determined and emphasized by this study. A recognition of these controlling factors may permit predictions as to the rate of nitrification of many materials yet untested and about which the farmer is now seeking information. The need for new experiments concerned with the rate of nitrification of roots, root-crops, roots and stubble, sods of various non-legumes, mixed sods, weeds, weed and crop mixtures, volunteer growths of various crops, second growths, crop residues, crop products, and many vegetable residues is apparent when one reviews the literature. Some of these untested farm materials constitute a larger factor in the farming practices than those already tested. In attempting to arrange a wide variety of substances from natural and prepared sources some difficulties are met as to proper placing of the intermediate mixtures and of some of the simpler compounds. A few will be cited here. Urea is now a synthetic product as well as an animal product. The same is true of guanidine. The sludges, while originating from processes concerned with the disposal of sewage, are high in bacterial cells and might be grouped with the micro-organic bodies. Farm manures are composed of much vegetable material such as straw, stalks, and litter, and not a small percentage is made up of bacterial cells, living and dead. The classification presented herein appears satisfactory for the purpose at hand and will be revised if better evidence accumulates in the future.

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[1] Paper read as a part of the symposium on "Soil Bacteriology--Nitrification Studies" at the meeting of the society held in Chicago, Ill., November 17, 1926. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station, Madison, Wisc.

[2] Associate Professor of Agricultural Bacteriology, University of Wisconsin.

Four main headings and two sub-divisions have been chosen for classifying the materials These are:

I. Chemical Products
II. Animal Products
III. Plant Products:
    Legumes
    Non-legumes
IV. Micro-organic Products

The rate of nitrification is represented in so far as possible by form of arrangement. The first group under each heading contains the most rapid nitrifiers and the rate decreases by groups in numerical order. Within the groups the order is in descending scale unless otherwise indicated.

It has been a difficult task to place properly some of the materials within the groups. The final decision was based upon the most complete trials found and the performance of the materials in as many cases as possible where conditions were definite and well controlled.

PROPOSED GROUPING OF ORGANIC MATERIALS AS TO RATE OF NITRIFICATION

I. *Chemical Products*

Group 1.	Group 2.
Amino acids	Peptone
Nucleic acid	Naphthylamine
Acid amids (urea)	

II. *Animal Products*

Group 1.
- Urea
- Alloxan
- Guanidine
- Urine, fresh
- Urine, stored
- Casein
- Albumin
- Gelatin

Group 2.
- Dried blood
- Fish, dried
- Fish, ground
- Fish guano
- Crayferine (fish by-products)
- Bird guano
- Bat guano
- Whale guano
- Flesh meal
- Roasted horn
- Tankage
- Bone meal
- Garbage tankage

Group 3.
- Sludges (activated)
- Sludges (tank)

Group 4.
- Liquid manure
- Solid and liquid manure
- Goat manure
- Sheep manure, rotted
- Sheep manure, fresh
- Cow manure, rotted
- Cow manure, fresh
- Horse manure, rotted
- Horse manure, fresh

Group 5.
- Horn trimmings
- Poudrette
- Roasted leather
- Leather chips

III. *Plant Products*
(Part 1 — Legumes)

Group 1.
- Alfalfa:
  - Tops, green
  - Tops and roots, green
  - Tops, flowering stage, green
  - Tops, dry (hay), young
  - Tops, dry (hay), old
  - Meal
- Sweet clover (biennial):
  - Tops, green, 2nd year
  - Tops and roots, green, 2nd year
  - Tops, 1st year, dry, young
  - Tops, 1st year, dry, old
  - Leaves, 1st year, green
  - Leaves, 1st year, dry
  - Stems, 1st year, dry
  - Roots, 1st year, dry
- Sweet clover (annual):
  - Tops, green
  - Tops and roots, green
  - Tops, flowering stage, green
- Red clover:
  - Tops, green, 1st year growth
  - Tops, cured 72 hours, 1st year growth

- Tops and roots, green, 2nd year growth
- Tops, dry (hay), young
- Tops, dry (hay), old
- Tops, flowering stage, green, 1st year

Alsike clover:
- Tops, dry, young
- Tops, old, and seeds

Group 2.

Sann hemp (*Crotalaria juncea*):
- Tops, green, 4 weeks growth
- Tops, green, 6 weeks growth
- Tops, green, early bloom
- Tops, green, cured 24 hours
- Tops, green, cured 48 hours
- Tops and roots, green, 6 weeksold
- Tops and roots, green, early bloom
- Leaves green, 6 weeks old
- Stems, green, 6 weeks old
- Roots, green, 6 weeks old
- Top stems, green, 6 weeks old
- Top stems, green, 12 weeks old
- Middle stems, green, 6 weeks old
- Middle stems, green, 12 weeks old
- Bottom stems, green, 6 weeks old
- Bottom stems, green, 12 weeks old

Dhaincha (*Sesbania aculeata*):
- Tops, roots, green, 6 weeks old
- Leaves, green, 6 weeks old
- Stems, green, 6 weeks old
- Roots, green, 6 weeks old

Black-eyed peas:
- Tops, flowering stage, green

Cowpea:
- Tops, green, flowering stage
- Tops and roots, green
- Tops, dry, young
- Tops, dry, old
- Roots and stubble, green
- Roots, green, 6 weeks old
- Stems, green, 6 weeks old
- Leaves, green, 6 weeks old
- Hay, dry
- Meal, dry

Field peas:
- Tops, green
- Tops and roots, green

Vetch:
- Tops, young, dry
- Tops, old, dry
- Tops, flowering stage, green
- Tops, green

    - Tops, hay, dry
- Soybean:
    - Tops, green
    - Tops and roots, green
    - Tops, dry, young
    - Tops, dry, old
    - Meal (seed?)
- Velvet bean:
    - Tops and roots, green, early bloom
    - Tops, dry, young
    - Tops, dry, old
- Lyon bean:
    - Tops, early bloom
- Mauritius bean:
    - Tops and roots, green, early bloom
- Cassia:
    - Tops, and roots, green early bloom
- Beggarweed:
    - Tops and roots, green, early bloom
- Kulthi:
    - Tops and roots, green, early bloom
- Lupin:
    - Tops and roots, green, early bloom
- Bur clover:
    - Tops and roots, green, early bloom
- Tangier pea:
    - Tops and roots, green, early bloom
- Lentil:
    - Tops and roots, green
- Fenugreek:
    - Tops and roots, green
- Guvar (*Cyanopsis psoraliodies*):
    - Tops and roots, green, 6 weeks old
    - Leaves, green, 6 weeks old
    - Stems, green, 6 weeks old
    - Roots, green, 6 weeks old
- Gokarn (*Clitoria ternata*):
    - Tops and roots, green, 6 weeks old
    - Leaves, green, 6 weeks old
    - Stems, green, 6 weeks old
    - Roots, green, 6 weeks old
- Peanut
- Tamarind (*Tamarindus indica*):
    - Tops and roots, green, 6 weeks old

(Part 2—Non-legumes)

- Group 1.
    - Corn:
        - Sweet, tops, flowering stage, green
        - Field, tops, flowering stage, green
        - Field, stalks, dry
        - Field, cobs, dry
        - Field, meal, dry

- Buckwheat:
  - Tops, flowering stage, green
  - Tops, well-blossomed, green
  - Tops, seeds forming, green
  - Tops, almost ripe, green
  - Tops, ripe, green
- Wheat:
  - Tops, green, flowering stage
  - Tops, headed, green
  - Stubble
  - Straw, dry
  - Flour
- Barley:
  - Tops, green
  - Tops, flowering stage, green
  - Tops (hay) dry
  - Straw, dry
- Oats:
  - Tops, green
  - Tops, young, dry
  - Tops, preceding boot stage, green
  - Tops, boot stage, green
  - Tops, flowering stage, green
  - Tops, fully headed, green
  - Tops, almost ripe, green
  - Tops, heads yellow, green
  - Tops, ripe, green
  - Straw, dry
  - Dust, dry
- Rye:
  - Tops, green, young, 1st year, fall growth
  - Tops, young, dry, 1st year, fall growth
  - Tops and roots, green
  - Tops, preceding boot stage, green, 1st year, spring growth
  - Tops, boot stage, green, 1st year, spring growth
  - Tops, blossoming, green, 1st year, spring growth
  - Tops, well headed, green, 1st year, spring growth
  - Tops, fully headed, green, 1st year, spring growth
  - Tops, almost ripe, green, 1st year, spring growth
  - Tops, heads, yellow, green, 1st year, spring growth
  - Tops, ripe, green, 1st year, spring growth
  - Straw, dry
  - Straw, green
  - Flour, dry

Group 2.

- Blue grass tops, green
- Timothy tops in bloom, green
- Timothy hay, dry
- Sorhgum tops, flowering stage, green
- Teff hay (grass for hay) dry
- Black Jack hay, dry

- Rice flour, dry
- Kelp, green
- Apple pomace
- Mixed weeds, dry:
  - Smartweed
  - Foxtail
  - Cocklebur
  - Ragweed

Group 3.
- Woods
- Tree products (leaves, bark, etc.)
- Sawdust
- Wood pulp
- Cellulose
- Resins, tannins, turpentine
- Petroleum, crude
- Starch
- Sugars

Special Group:
- Legumin
- Zein
- Hordein
- Linseed meal
- Cottonseed meal
- Tea leaves
- Oil-free tili cake
- Castor cake (*Ricinus latifolia*)
- Karanja cake (*Pongania glabra*)
- Sarson cake (*Brassica napus*)
- Tili cake (*Sesamun indicum*)
- Mahua refuse (flowers of *Brassica latifolia*)
- Piperidine
- Pyridine
- Quinoline
- Mahua cake (*Brassica latifolia*)

IV. *Micro-organic Products*

Group 1.
- *Fusarium bullatum*, dead, dry, ground
- *Mucor spinosus*, dead, dry, ground
- *Rhizopus tritica*, dead, dry, ground
- Azotobacter, dead, dry, ground
- *Aspergillus niger*, dead, dry, ground
- *Cladosporium herbarum*, dead, dry, ground

Group 2.
- *B. mycoides*, dead, dry, ground
- *Actinomyces penicilloides*, dead, dry, ground

I. CHEMICAL PRODUCTS

The chemical products nitrify very rapidly and in general up to about 85 to 90% of their nitrogen often in only 10 to 14 days. The amino group of the amino acids is hydrolyzed or removed very fast by soil bacteria and yields ammonia which is rapidly oxidized to nitrate. The acid amides are nitrified practically as rapid as most of the amino acids. Nucleic acid is very closely associated with these rapid sources of nitrate. These materials are water soluble for the most part. Peptone is a biologically pure, secondary product of protein hydrolysis. It hydrolyzes so rapidly that it undergoes a high speed of nitrification. It is also very soluble and diffusible. Napthylamine is a prepared chemical, only very slightly soluble in water, and does not occur in nature. It nitrified very slowly in the few studies reported. It contains 9.79% nitrogen and has a C–N ratio of 8.5 to 1.

The materials under this heading are all high in nitrogen, containing from about 7.7 to 21.2%. They are also high in carbon, varying from 32 to 83.9% with ratios of C to N from 1.7 to 1 to 8.5 to 1, with many ratios as narrow as 3 to 1. Many of these chemical products are water soluble and all contain nitrogen in rapidly hydrolyzable forms.

II. ANIMAL PRODUCTS

The materials occurring under the heading "Animal Products" have been arranged in five groups. The first group includes urea, related substances, and some biologically pure proteins. These materials closely approach those under the heading "Chemical Products" in their rate of nitrification. Urea is more rapid than peptone and possibly as rapid as any of the amino acids. The simpler substances are very soluble in water, high in nitrogen, and somewhat unstable. Urea contains 46.44%, guanidine carbonate 46.62%, and alloxan 19.71% of nitrogen. The C–N ratio of urea is 1 to 2.3; of guanidine carbonate, 1 to 2.4; and of alloxan, 1.2 to 1.

Casein, albumin, and gelatin contain 16 to 18% of nitrogen and 49 to 53% of carbon, making their C–N ratios 2.7 to 3.3 to 1. These proteins are easily hydrolyzed and rapidly yield water-soluble nitrogen.

The members of group two are not arranged according to their rate of nitrification. This was not possible as the fish products and guanos have exceeded dried blood in some trials, but not in all. There is little choice in the list down as far as tankage. The last three members are slower than the others.

The fish products are high in nitrogen and are easily hydrolyzed. The guanos contain uric acid, urates, and ammonia, which are large factors in their initial rate of nitrification. They also contain from 5 to 8.5% of total nitrogen. Aside from the garbage tankage, cellulose is not a constituent of the materials in this group. The proteins are less resistant to hydrolysis than those found in plant products.

Group three composed of activated and tank sludges vary in percentage of nitrogen from 1.23 to over 7. The tank sludges have been found to have the lower nitrogen content. Many workers consider the sludge material as micro-organic cells. Sludges are not quite as rapid as blood in the production of nitrates. They are placed in a separate group under animal products, but may in the future be found to be so similar in speed of nitrification to bacterial and protozoal cells as to be included in the same group with such sources of nitrogen. This source of nitrogen bids fair to become increasingly important in the future. These sludges have a C-N ratio varying from 40 to 1 to as narrow as 6.5 to 7 to 1. They contain bacterial proteins surrounded by a cell wall, not, however, supposed to be as resistant as cellulose.

The farm manures are placed in a separate group. In most experiments they have been slow sources of nitrates, falling much below the other groups already considered and below many of those under legumes and non-legumes.

It is very apparent that the preservation of the urine increases the speed of nitrification of these farm manures and that the practice of rotting manure improves its nitrification. The fresh manure properly handled may carry much soluble nitrogen which will give a rapid production of nitrates, while the process of rotting rids the manure of the retarding action of straw, litter, and cellulose materials. The nitrogen content of the farm manures varies between 1.20 to 2.46% and the C N ratios vary from 9.7 to 1 to over 25 to 1.

Many of the experiments with manures show negative results from the standpoint of nitrification during the first two or three months.

The remaining group under animal products is very slow in its nitrification as would be predicted because of the resistant forms of the nitrogen they represent. They are not, however, low in nitrogen. While slow, no evidence of negative action has been found.

The groups under the heading "Animal Products" represent wide extremes of rate of nitrate production. Group 1 is very rapid, while Group 5 is probably the slowest of all the materials to be considered. The groups represent materials of very high nitrogen content and very low nitrogen content, while the ratios of C–N vary widely from 1 to 2.4 to the high ratio of 40 to 1.

Urea is the outstanding material for rapid nitrification, and because it is made synthetically it might have been included under "Chemical Products." Materials derived from urea and containing it and its derivatives are next rapid in nitrification. The more of the urea, uric acid, and replaced products in the farm manures the faster they become as nitrifiers in the absence of excess straw.

There are two rapid groups under this heading, while the third is slower, but gives nitrates. The last two, especially the farm manures, are the least dependable, more frequently reducing the nitrate already present than adding to it in the initial periods.

The largest, most important, and by far the most interesting class of materials will be considered next under "Plant Products."

III. PLANT PRODUCTS

Two sub-divisions have been made under this heading, *viz.*, Part 1, Legumes; and Part 2, Non-legumes. The legumes as a class are nitrified distinctly faster than the non-legumes and consequently are placed first under this heading. The plant products are arranged with the young green tops and parts at the top of the list as the most rapid. These are followed by tops of increasing maturity which in turn are followed by the dry and mature plant products with the youngest of these preceding the oldest. A few special products are also included at the close of the list under each plant where such products have been tested.

It should be understood that green young tops from a plant low on the list may surpass a dry plant product listed much higher, and a young plant product may likewise surpass an older one listed above it in a plant of another kind.

PART I. LEGUMES

Two groups have been recognized among the legumes. The first group is headed by alfalfa and sweet clovers and the evidence indicates no essential differences between them in the rate of nitrification. Sweet clover is more usable for rapid nitrification in actual practice, while green alfalfa tops have always given such a high rate of nitrification as to be considered equal to sweet clover. Red and alsike clover are less rapid in nitrate production than sweet clover and alfalfa.

The annual legumes of this group are rapid nitrifiers but have not given the same speed as the alfalfa, sweet clovers, red, and alsike clovers. More work is needed on some of these legumes for final order of nitrification. They can often be used when the biennial and perennial legumes are not available for green manure purposes. Where speed of nitrate production is necessary in early spring, biennial sweet clover is recommended. Alfalfa may also serve the purpose in some cases. In the summer and fall, many legumes are suitable. Among the annuals, sweet clover is perhaps the best for fall nitrification. For rapid summer nitrification, the young green tops of cowpeas, sann hemp, soybeans, and many legumes untried in this country should be considered.

There is complete agreement in the literature as to the superiority in rate of nitrate production of the green legumes over the dry, although both contain the same C-N ratios and the same total nitrogen. As indicated from the order of arrangement the younger the tops and roots are the more rapid is their nitrification either in the green condition or in the dry condition.

The nitrogen content of alfalfa, sweet clover, and the common clovers is highest when the plants are young. High nitrogen content might be considered as associated with rapid nitrification and frequently is, but high nitrogen is not necessarily the determining cause of a rapid nitrification. It is well to bear in mind that these rapidly nitrifying legumes have a high carbon content containing about 45% of that element Their C N ratios vary from about 20 to 1 to 8 to 1.

There are other important factors besides the total nitrogen and C-N ratio that influence the speed of nitrification of such materials, but their discussion will be deferred until the other materials have been considered

The annual legumes grow rapidly and mature rapidly. The cellulose of these legumes is made resistant rapidly, and the nitrogen is rapidly laid down in the seed in a stable form. When used as a green manure in cases where a rapid nitrate production is needed, they must be applied or incorporated when still green and as young as possible.

PART 2. NON-LEGUMES

Among the non-legumes three groups have been made. The first group is distinctly superior to the others in speed and quantity of nitrates produced. It is not, however, as a group, as rapid as the annual legumes The green young plants in Group 1 have been positive in their nitrification in the majority of the cases. Sweet corn and field corn in the green condition at the flowering stage lead this group. The nitrogen content of the corn plant is high at this stage and the proportion of cellulose low. Buckwheat is much superior to the small cereal grains. Even at the flowering stage, although applied green, rye and oats have fallen below the untreated soil in some trials. Rye, a much used non-legume, is the poorest of this group. It has been used because of its hardiness rather than because of its value as a source of nitrates.

The striking difference between the non-legumes and the legumes is the fact that the non-legumes become negative in rate of production of nitrates, holding the accumulation below the untreated soil. This occurs even in the green condition at approaching maturity, and is very generally the rule in the dry condition at maturity. This negative action persists for some weeks, after which nitrification proceeds normally, but for the purpose of this study they are negative. This change from positive to negative nitrification comes rapidly when many of the non-legume crops are about half grown.

The recognized depressing action of the straws, at least in the accumulation of nitrates if not on the production of them, is too well established to need extended consideration here.

Group 2 is composed of crops and materials giving no nitrates in the early stages. An exception is again made for the green bluegrass and green timothy. All the others gave no nitrate and many reduced the nitrate originally present in the soil. The slow nitrate production of such non-legumes needs more emphasis in soil teachings.

Group 3 consists of wood and wood products, cellulose, oils, starches, and sugars, all of which depress nitrate production until they have been reduced in concentration or changed to simpler products. Sugar exerts the most rapid depressing effect on nitrate accumulation but its effect is the least enduring. Starch follows next in order, and then cellulose, with tree products, wood, and sawdust exerting their effect slowly sometimes at first and often over a long period. Even variations are found here among the different kinds of woods, depending perhaps upon their rate of decomposition.

Petroleum depresses nitrate production at first, even in small amounts, but later it proceeds at least normally. A special group, containing vegetable proteins, linseed oil meal, cottonseed meal, tea leaves, and some plant alkaloids, is arranged because of the limited use of such materials in soils. These special materials are very rapid in nitrate production. The plant proteins were not accompanied with cellulose in these tests. Linseed oil meal has been more rapid than cottonseed meal, while cottonseed has in some experiments proved better than dried blood.

This group is characterized by high carbon and high nitrogen contents, a narrow C–N ratio, and relatively rapid hydrolysis.

IV. MICRO-ORGANIC PRODUCTS

Very little work has been reported on the rate of nitrification of bacterial cells. The two groups are arranged because of the apparently wide difference between the members. Possibly activated sludge should be included in this group, but more work will be necessary before this can be decided. It is interesting to note that the voluminous fungous growth is more rapid in its nitrification than the bacterial cells. Some of these materials were more rapid than alfalfa meal, cottonseed meal, and green rye, but not as rapid as dried blood.

DISCUSSION

The listing of these organic materials in the suggested outline based upon their performance in as nearly comparative experiments as possible makes it convenient for consideration of the fundamental factors controlling the rate of nitrification.

In the literature on the subject several outstanding conclusions are found and these will now be discussed.[3]

The C–N ratio is considered by some as the controlling factor in the rate. The total nitrogen content has been emphasized by a number of workers The ease of hydrolysis and the lack of cellulose to hinder rapid action by the nitrifying organisms has been pointed out by a few investigators. The unstable nature of animal proteins led some early experimenters to place them ahead of the vegetable proteins in rate of nitrate production.

The writer and many other investigators have almost unanimously found the green condition of legumes and non-legumes to possess a much faster rate of nitrate production than the dry materials of the same kind and age.

Two different views exist as to the cause of the depression or complete suspension of nitrate accumulation which results when many highly carbonaceous materials are applied to soils

The one assumes that the nitrates are produced and are used as food by the various soil bacteria which accounts for no accumulation. The other maintains that the decreased nitrate accumulation is due to decreased activity or complete cessation of activity of the nitrifying bacteria. This condition being brought about by supplying a source of energy for non-nitrifying organisms causes them to thrive and to use up the nitrate present.

The experimental data available for study do not support or refute either view with completeness. The initial nitrate in a soil may almost disappear, or it may be added to in a smaller way than in the controls. The first suggests no activity, while the second proves some activity if the amount of nitrate found at the end is greater than at the start. It seems to the writer that the conditions studied thus far represent both a stopping and a checking of the activity of the nitrifying bacteria. Substances have been tested that permit ammonification, but no nitrification, which indicates that many of these organic substances that prevent accumulation may be acting in a similar manner to stop the nitrite and nitrate bacteria from functioning.

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[3] See "Literature Reviewed," p. 872.

The microbial equilibrium of a soil must be displaced in favor of organisms utilizing carbon from organic sources when additions of large amounts of that element are made, and likewise when the nitrogen additions are sufficiently large, the nitrifiers produce in excess of the consumption of other bacteria which can hardly be expected to reach their maximum activity under such conditions. As these nitrifiers are autotrophic, organic carbon is not necessarily a requirement of their growth but nitrogen is. This fact lends support to the idea that nitrifying organisms are at a decided disadvantage when relatively large amounts of certain forms of carbon and small amounts of nitrogen are added.

THE C–N RATIO AND THE RATE OF NITRIFICATION

In the discussion of the rates of the various groups, the C–N ratios of numerous materials have been given. Some of these have been brought together in Table 1. It is very evident that the ratio is not a large factor in the rate if the outline is considered as a whole. Some materials with a narrow ratio of 3 to 1 are the most rapid of all of a given group. Even the inverse ratios are still more rapid in nitrate production. Some of the materials with a ratio of 25 to 1 are very rapid in their production of nitrates, and while not approaching those with the narrow ratios (3 to 1, 7.7 to 1), greatly exceed materials with a ratio of 15 to 1, 0.7 to 1, or 13 to 8 to 1, and those with wider ratios of 250 to 30 to 1.

With a high carbon content and a low nitrogen content nitrates may be produced slowly or not at all or they may be produced rapidly provided the carbon is not in a resistant state and the nitrogen of average to high content. Even with the carbon in a resistant condition, nitrates are formed rapidly if sufficient organic or inorganic nitrogen is present or is added to give the nitrifiers the advantage. Cellulose and straw check nitrate accumulation until the nitrogen added brings the ratio to about 15 to 18 of carbon to 1 of nitrogen. If one only considered cellulose and straw, there might be a basis for the ratio view, but the same organisms nitrify rapidly regardless of the ratio in other materials.

The same retarding effect represented by cellulose and straw begins to be increasingly evident in plants with the progressive approach towards maturity.

The percentage composition of a plant varies very little in carbon from the young condition to the old. Most plants average about 45 to 50% carbon. The carbohydrates are so nearly of the same percentage and so near that of the proteins that the total percentage of carbon is kept about constant or in some cases decreases and in others increases slightly. The changes in carbon percentage decrease without much effect on the relation the total carbon maintains to the rest of the organic matter.

The form in which the carbon is present in plant products appears to be a factor that must be taken into consideration. The fractions which make up the total carbon content need to be examined.

It seems probable that cellulose, starch, sugars, and related materials may interfere with the rate of decomposition in most of the plant and micro-organic materials. With high nitrogen the effect may not be evident. When amino acids, amids, and proteins unaccompanied by cellulose are examined, there seems to be little depressing action of the carbon which is present in amounts averaging about 50%. The rate of nitrification of the high-nitrogen-containing materials is so fast that sufficient nitrate accumulates for rapid crop growth.

Thus the C:N ratio when taken on the basis of total carbon and total nitrogen does not appear to be an important general factor controlling the rate of nitrification of the materials herein considered. It is not to be understood, however, that there is no C–N ratio influence in the plant materials, but even here it seems not to be related

TABLE 1 — *Carbon-nitrogen ratios and percentages in some organic materials.*

Materials	Percentage limits		Ratio limits	
	Carbon	Nitrogen	Carbon	Nitrogen
Urea	20	46.4	1	2.3
Guanidine	18.8	46.6	1	1.4
2 amids	36.4–41.1	19.2–21.2	2.1– 1.7	1
10 amino acids	32 –65.5	8.5–19.2	7.7– 1.7	1
12 proteins	49.4–55.2	15.7–18.3	3.4– 2.7	1
Crops with 2–6% nitrogen	40 –50	2 – 6	25 – 6.6	1
Vetch	41.3	4.0	10.3	1
Clover hay	41.3	2.1	20.0	1
Cowpea hay	42.2	2.2	19.3	1
Cow manure	36.6	2.4	15	1
Rotted manure	23.9	2.4	9.7	1
Horse manure	38.8	1.6	23.5	1
Crops with 0.2–2% nitrogen.	40 –50	2 – 0.2	250 –20	1
Timothy hay	38.2	0.97	39.2	1
Straws	39 –45	0.5– 1.3	90 –40	1
Corn stover	39.8	1.5	27	1
Cellulose, sugar, pentosans, hexosans.	40 –45.5			
Soil organic matter			13 – 8	1

to the ratio as much as to the fractions constituting the carbon content. There is also a strong suggestion that the increased quantities of certain carbon materials are the cause of depressed nitrate production. The more carbon present the more difficult it is for the nitrifying bacteria to establish contact with the nitrogen and the more work to be done by cellulose fermenters.

TOTAL NITROGEN CONTENT AND THE RATE OF NITRIFICATION

The total nitrogen content of the materials considered varies from no nitrogen to compounds containing as high as 46% of that element. It is quite the general rule for the materials containing the higher nitrogen contents to be more rapid in nitrate production. This is not true, however, of all materials. A few high-nitrogen-containing materials have the nitrogen in a very resistant form and withstand the bacteria for years and a few low-nitrogen-containing materials show a rapid nitrification.

WATER SOLUBLE NITROGEN AN IMPORTANT FACTOR IN RATE OF NITRIFICATION

A study of the solubility of the nitrogen contained in the materials leads to the conclusion that it is the largest factor in the initial rate with most materials. The amino acids, amids, urea, and soluble proteins are the most rapid, some even being as rapid as inorganic ammonium salts. The effect of soluble nitrogen is seen in a number of the materials, such as guanos, urine, liquid manure, dried blood, alfalfa, sweet clover, and in the green and the young plants. This matter of water-soluble nitrogen has not been given sufficient consideration in the studies made. The results in Table 2 were obtained by Whiting and Richmond and serve to indicate the importance of the water-soluble nitrogen as the largest factor in the initial rate of nitrification of a sample of sweet clover roots.

TABLE 2.—*Relative rate of nitrification of parts of sweet clover as influenced by percentage of water-soluble nitrogen.*

15 mgs. per 100 grams of soil.

Part	Total nitrogen %	Water-soluble nitrogen %	Percentage nitrified 1 month	Percentage nitrified 2 months	Percentage nitrified 3 months
Leaves	3.42	33.3	6.7	69.3	100
Stems	1.35	37.3	0.9	—	8.4
Roots	2.82	86.6	37.3	82.7	69.3
Whole plant	2.50	67.3	9.3	61.3	47.0

The high content of water-soluble nitrogen in the fibrous roots of the biennial sweet clover controls the rate of nitrification of the entire plant and even surpasses the leaves. This water-soluble nitrogen dominates the rate of nitrification in spite of the high carbon and only 2.50% of total nitrogen. The rate shown by the leaves is accounted for on the basis of high water-soluble and high total nitrogen contents and non-resistant carbon content.

The rate found for the stems is in accord with ideas already presented. The stems are low in total nitrogen, high in water-soluble nitrogen and resistant carbon, and carry more than twice as much of it as carried by the leaves or a poorer distribution or placement exists in the stems if one wishes to call it that.

In considering the relation of water-soluble nitrogen to speed of nitrification one should not overlook the fact that the water-soluble nitrogenous compounds may often contain 15 to 19% of nitrogen. This would represent a much better opportunity for contact than found in the original material even though high in nitrogen.

It might be thought that the condition of a high water-soluble nitrogen content was limited to the roots of a biennial crop preparing for winter storage, but this is not the case.

Osborne, Wakeman, and Leavenworth found that 43.8% of the total nitrogen of green alfalfa tops was water soluble. Ames and Boltz reported 50% in first and second cuttings of alfalfa tops. Other determinations on dry alfalfa by Whiting and Richmond gave 49% for young alfalfa tops and 42% for older alfalfa tops. Grindley and Epstein reported 28.4% water-soluble in dry alfalfa hay. Leukel,[4] in a study of root reserves of alfalfa made at Wisconsin, has found a high content of water-soluble nitrogen the first year.

UNSTABLE AND EASILY HYDROLYZABLE NITROGEN

The rapid nitrification of certain materials is traceable to the unstable nature of the protein and its derivatives contained in them. The high content of protein subject to easy hydrolysis in a number of substances, is accompanied with sufficient water-soluble nitrogen and devoid of cellulose or other interfering materials as to give them a very high rate of nitrification. This condition of easily hydrolyzable nitrogen is associated with high nitrogen content.

These materials are largely animal or chemical products as the plant proteins are seldom applied to soil in quantity without the accompanying cellulose. In young and especially green plants the nitrogen compounds for the most part are more easily hydrolyzed than when older and dry.

GREEN CONDITION COMPARED WITH DRY CONDITION

There is almost complete agreement in the literature showing the green condition of plants and plant products to be much faster in nitrate production than the dry condition.

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[4] **Leukel, W. A.** Unpublished data, University of Wisconsin.

In these cases another factor than chemical composition enters. The carbon and nitrogen contents are the same and the ratio the same, or nearly so, in both the green and dry materials. The fraction of the total carbon would not be very different in the two cases. The water-soluble nitrogen is assumed to be somewhat less in the dry materials than in the green. Drying does not mature the crop as in natural maturity and yet this process leaves its stamp on the rate by reducing it. A physical shrivelling of the cell walls after removal of the water retards its reentrance into the hydrophylic colloids sufficiently to reduce considerably the rate of nitrification. This is believed to be a large factor in permitting the bacteria to attack the materials in the cells of plants not ruptured

MATURITY AS A FACTOR IN RATE OF NITRIFICATION

The groups under legumes and non-legumes indicate that the coming of maturity is a large factor in the rate of nitrification of plant products. This holds true for both the green and the dry condition. The development of maturity decreases the total nitrogen content, increases the resistant carbon content, reduces the water-soluble nitrogen content, and removes water from the internal contents of the plants.

The legumes seem to be positive in nitrate production even at maturity, while most non-legumes are negative even before maturity while yet still somewhat green

It is evident from the foregoing discussions that the solubility of the nitrogen is the most important factor in the rate of nitrification. This factor is closely associated with cell activity in plants, which in turn involves a high content of relatively unstable and easily hydrolyzable nitrogen. It is further a part of a condition in which the cellulose and carbonaceous materials are not in a resistant form and in which the chance of contact with nitrogen by the nitrifying bacteria is greater than in older material, where more resistant carbon is present with less soluble nitrogen and a smaller total amount of that element, in a more stable form. A study of many materials from the standpoint of contact of the nitrifying organisms with the nitrogen in the material should be made. The speed of nitrification may be dependent upon the contact the nitrifying bacteria are able to make with the nitrogen in the compounds and even in the molecule.

The amount of carbon present in the material appears not to be a factor if the nitrogen is high, but is a large factor when the nitrogen is low. It depresses and may even stop nitrate production whether in the same material or in another material. The fractions of the total carbon need special study from the standpoint of their effect upon the nitrifying organisms and the temporary unbalancing of the microbial equilibrium existing in normal soils. If a preference for certain carbon sources on the part of some of the ammonifiers occurs, it would account for none or for a limited source of nitrogen for nitrate formation until the carbon source had been reduced or used up.

The following conclusions are derived from this study and are fundamental factors concerned with the rate of nitrification. They may be of assistance in predicting the rate of nitrification of many materials.

CONCLUSIONS

1. The water-soluble nitrogen content of the material determines to a large extent the rate of nitrification in the initial periods.

2. A high total nitrogen content is conducive to a rapid nitrification and is usually accompanied with a high water-soluble nitrogen content.

3. A high content of easily hydrolyzable nitrogen gives a very rapid nitrification if unencumbered with cellulose.

4. Green plant products nitrify more rapidly than dry plant products of same age and kind.

5. Young plant products nitrify more rapidly than older ones of the same kind.

6. Legumes are more rapid in nitrification than the non-legumes.

7. The relation of carbon to the production of nitrates in the early stages of nitrification is not yet proved. Some contend that a toxic effect exists, some a depressing effect, and some no effect. The influence of a ratio, if such exists, is limited to a very few materials.

8. Over 200 organic materials have been classified tentatively under four main headings, two sub-divisions, and by groups under the headings as to rate of nitrification.

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4. STUDIES ON THE NITRIFICATION OF AMMONIUM SULFATE IN SOIL[1]

HORACE J. HARPER AND BRYAN BOATMAN[2]

Although nitrification has been studied more extensively than any other biological activity occurring in soils, there seems to be little agreement regarding the methods of investigation and the value of the data obtained. This is probably due to the wide variation in the physical and chemical properties of soils in various regions, and in the microbiological activities occurring in them. It is entirely possible, however, that data which appear to disagree might not do so if sufficient information had been given by the various investigators on the physical and chemical properties of the soils studied and on the crop or cropping system to which the soils had been subjected, all of which have a direct bearing on the nitrification process.

EXPERIMENTAL

The first portion of this investigation was devoted to a study of methods, with particular reference to the amount of ammonium sulfate to use in testing soils for their nitrifying power and to the length of the incubation period. Certain methods have been used more than others during the past few years, and it seemed desirable to determine whether these methods really give superior results. The amount of ammonium sulfate which has been proposed by previous investigators (4), (6), (7), (13), (16), and (18)[3] varies from 100 milligrams to .1 gram per 100 grams of soil, or if calculated on an acre basis, 2,000 to 20,000 pounds of ammonium sulfate per 2,000,000 pounds of soil. These amounts are considerably higher than those which are usually applied to field soils, and it does not seem reasonable to believe that data obtained under such conditions would necessarily show accurately the nitrifying power of soils in the field.

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[1] Paper read as a part of the Symposium on "Soil Bacteriology—Nitrification Studies" at the meeting of the Society held in Chicago, November 17, 1925. Contribution from the Iowa Agricultural Experiment Station, Ames, Iowa.

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The time of incubation which has been used is also quite variable. Some investigators have used a short incubation period, analyzing their soils in seven days after inoculating them, while others have allowed their tests to incubate for six weeks. A shorter period of incubation certainly would be preferable if the data obtained are as valuable as those secured when a longer incubation is practiced.

In the first experiment three moist soils were used to determine the effect of varying amounts of ammonium sulfate and of different incubation periods on their nitrifying powers. A brief description of these soils is given in Table 1.

TABLE 1.—*The total nitrogen, organic matter content, and the reaction of the three soils used in the first experiment.*

Soil type	Total nitrogen, pounds per 2,000,000 pounds of soil	Organic matter content	Reaction	Crop grown
Webster silt loam	7,850	High	Basic	Oats
Carrington loam	3,400	Medium	Medium acid	Corn
Lindley fine sandy loam	1,000	Low	Neutral	Wheat

The method used for determining the nitrifying power of these soils was as follows: 100-gram portions of soil (air-dry basis) were placed in glass tumblers and treated with varying amounts of ammonium sulfate equivalent to 10, 20, 30, 40, and 50 milligrams of nitrogen. The ammonium sulfate was added in solution and in each case the dilution was such that the correct amount of salt was contained in 5 cc. The tumblers were covered with metal lids and allowed to stand for 30 minutes, or as long as 2 hours in the case of some heavy soils which were low in organic matter. The soil was then transferred to an 8-inch evaporating dish and thoroughly mixed in order to secure a uniform distribution of the ammonium sulfate. Each soil was returned to a glass tumbler, uniformly packed with a 1-kilogram weight, made up to the optimum moisture content with distilled water, and placed in the incubator which was kept at a temperature of 25° to 27°C. The soils were kept at the optimum

[3] Reference by number is to "Literature Cited," p. 887.

moisture content by adding water every seven days. The time of incubation was 10, 15, 20, and 28 days. All treatments were made in triplicate and duplicate nitrate determinations were made on each sample of soil using the phenoldisulfonic acid method (11). The results are given in Table 2.

In the case of the Webster silt loam which contains about 5% calcium carbonate, the amount of nitrate increased as the amount of ammonium sulfate and the length of the incubation period were increased. The Carrington loam did not respond to an increase in ammonium sulfate until the last incubation period which is due to the fact that the smaller application was nearly all nitrified and any further increase would have to come from the nitrification of the soil nitrogen. The Lindley fine sandy loam showed a lower nitrifying power during the first incubation period when the larger amounts of ammonium sulfate were added. During the other periods of incubation, however, a greater nitrifying power was obtained from the larger applications of ammonium sulfate than from the smaller treatments. However, a higher percentage of ammonia was converted to nitrate in most cases when the smaller applications of ammonium sulfate were made This agrees with the data of Kelley (13) and others.

When 10 milligrams of nitrogen as ammonium sulfate were added to these soils, it is evident that a shorter period of incubation than 28 days must be used if the data obtained are to be of any value, since in these soils which are distinctly different in crop producing power and also in biological activities, the amount of total nitrate at the end of the experiment was nearly the same, whereas at the end of 10 days there was a very marked difference in favor of the Webster silt loam which is the most fertile soil. Similar results were obtained with the 30-, 40-, and 50-milligram treatments which were incubated for 28 days, but there are several objections to such large applications. In the first place the measurement of the nitrate content of these soils by the method used required many dilutions and hence was undesirable. In the second place, such treatments have a very depressing effect on the nitrification taking place in very acid soils, and also in sandy soils, both of which may show an active nitrifying power when smaller amounts of ammonium sulfate are used in the tests This point will be brought out more fully in the succeeding paragraphs.

In the next experiment, a study was made in order to determine whether or not air drying would seriously affect the nitrifying power of field soils. Hall (8) has discussed this factor as follows, "It has

TABLE 2.—*The effect of additions of various amounts of ammonium sulfate and time of incubation at a temperature of 25°C. on the nitrifying power of three different soils.*

Soil type	Water content		Mgs. N. as $(NH_4)_2SO_4$ added	Nitrogen as nitrate in soils in parts per million																		
				10 days					15 days					20 days					28 days			
	Original	Optimum		1	2	3	Ave.	Percentage N nitrified	1	2	3	Ave.	Percentage N nitrified	1	2	3	Ave.	Percentage N nitrified	1	2	3	Ave.
	%	%																				
Webster silt loam	21.0	26.0	none	32.0	32.0	32.0	32.0	——	40.0	39.0	41.0	40.0	——	36.7	36.7	36.0	36.4	——	41.9	43.2	43.2	42.7
		26.0	10	102.4	102.4	107.8	104.2	72.2	116.0	128.0	122.0	122.0	82.0	120.0	122.5	130.8	124.4	88.0	136.0	136.0	140.0	137.3
		26.0	20	128.0	112.0	112.0	117.3	42.6	132.0	132.0	134.0	133.3	46.7	144.0	141.2	141.2	142.1	52.8	146.5	152.0	154.8	151.1
		26.0	30	137.7	134.5	123.2	113.8	33.3	188.0	204.0	208.0	200.0	53.3	242.0	256.0	240.0	246.0	70.0	309.1	——	330.5	319.8
		26.0	40	139.3	140.8	147.2	142.4	27.6	204.0	220.0	220.0	214.6	43.6	236.0	236.0	240.0	234.0	49.4	320.0	——	352.0	334.0
		26.0	50	147.2	144.0	140.9	144.0	22.4	228.0	236.0	232.0	232.0	38.4	248.0	248.0	248.0	248.0	42.9	341.0	363.0	357.0	353.7
Carrington loam	17.6	22.6	none	17.6	17.6	18.4	17.8	——	24.6	22.6	22.6	23.3	——	19.6	19.6	20.8	20.0	——	30.6	29.5	29.9	30.0
		22.6	10	48.8	48.1	51.3	49.4	31.6	78.0	72.0	80.0	76.6	53.3	84.0	82.0	84.0	83.3	63.3	122.7	128.0	133.2	127.9
		22.6	20	47.3	51.3	50.5	49.7	15.9	78.0	76.0	78.0	77.3	27.0	88.0	82.0	86.0	85.3	32.6	136.0	136.0	128.0	133.3
		22.6	30	48.8	50.5	48.0	49.1	10.4	76.0	76.0	80.0	77.3	18.0	88.0	84.0	86.0	86.0	22.0	144.0	140.6	156.0	146.9
		22.6	40	51.3	52.1	46.4	49.9	8.0	74.0	74.0	80.0	76.0	13.2	90.0	86.0	88.0	88.0	17.0	152.0	156.0	152.0	153.3
		22.6	50	52.1	49.7	49.7	50.5	6.5	76.0	74.0	76.0	75.3	10.4	88.0	84.0	86.0	86.0	13.3	148.0	144.0	——	146.0
Lindley fine sandy loam	11.1	16.1	none	14.9	14.9	14.7	14.8	——	21.2	21.2	21.2	21.2	——	20.0	18.4	19.2	19.2	——	30.7	29.9	30.6	30.4
		16.1	10	67.2	76.8	65.7	70.5	55.7	104.0	112.0	108.0	108.0	86.8	106.0	108.0	114.0	109.3	90.1	148.0	136.0	136.0	140.0
		16.1	20	62.5	68.8	68.8	66.7	25.9	114.0	118.0	118.0	116.6	43.9	114.0	116.0	122.0	117.3	49.0	144.0	148.0	152.0	148.0
		16.1	30	56.0	59.2	56.0	57.1	14.1	108.0	120.0	124.0	117.3	32.0	180.0	176.0	184.0	180.0	53.6	256.0	240.0	236.0	244.0
		16.1	40	59.2	56.0	60.8	58.6	10.9	132.0	128.0	128.0	129.3	27.0	156.0	156.0	164.0	158.6	34.8	236.0	242.0	240.0	239.3
		16.1	50	54.4	56.0	56.0	55.4	8.1	132.0	128.0	128.0	129.3	21.6	152.0	152.0	168.0	157.3	27.6	240.0	232.0	232.0	234.6

now long been an established fact that if a soil is air dried in the laboratory and then subjected to nitrification tests, it gives better results than the same soil not allowed to dry." However, a sufficient amount of data did not come to the attention of the authors in their review of the literature to substantiate the statement just quoted, and an experiment was conducted as follows: Seven moist soils from various parts of Iowa were secured for the test. Each sample was thoroughly mixed and divided into two portions, one of which was allowed to air dry in the laboratory for 48 hours. The other portion was placed in a sealed jar during this period in order to prevent loss of moisture. The nitrification tests were conducted as described in the previous experiment using 30 milligrams of ammonium sulfate per 100 grams of soil, air-dry basis. All treatments were made in triplicate and the data given in Table 3 are the averages of duplicate determinations.

It is evident from the data given in Table 3 that air drying soils may result in either a decrease or an increase in the nitrifying power or it may not have any effect. Since it is not uncommon in most sections of the country for field soils to become air dry to a depth of several inches and since several of the soil samples secured for the nitrifying tests which are reported in this paper were air dry when taken in the field, it was decided to air dry all samples in order to eliminate any error which might be due to differences in the physical condition of the moist and air dry samples.

After the experiments which are reported in the following pages were completed there was still some doubt in the minds of the authors as to the accuracy of the conclusions drawn from the data given in Table 3. Consequently another experiment was conducted on the effect of air drying on the nitrifying power of several soils obtained from different plats on the agronomy farm of the Iowa Agricultural Experiment Station. The results of this experiment are given in Table 4.

The data given in Table 4 are very similar to those presented in Table 3. In the case of the dry sample of Webster silt loam receiving 30 milligrams of ammonium sulfate, it was evident that the physical condition of this soil was not as good as that of the moist soil. In the case of the Carrington loam which had been air dried in the laboratory for eight weeks the nitrifying power was about the same as that shown by the sample which was dried only 48 hours. With this soil the original nitrogen present was nitrified more readily when the soil was moist than when it was air dried before being tested. However, in the case of the other two soils more nitrate was formed in the dried samples than in those which were kept moist before treatment.

TABLE 3.—*The effect of air drying on the nitrifying power of seven soils when incubated with ammonium sulfate at a temperature of 25°C.*

No.	Soil type	Moisture content		Nitrogen as nitrate in parts per million							
		In field	Optimum	Moist soil			Average	Dry soil			Average
		%	%								
1	Webster silt loam	30.7	35.7	100.0	100.0	100.0	100.0	91.0	88.2	91.0	90.0
2	Carrington loam	15.7	20.7	53.5	46.8	50.8	50.3	41.4	38.8	40.2	40.1
3	Marshall silt loam	12.3	28.0	86.9	85.6	84.2	85.5	91.2	92.2	91.0	91.3
4	Wabash silt loam	21.2	30.0	85.6	101.3	88.2	91.7	121.3	118.8	117.4	119.1
5	Tama silt loam	21.9	28.0	93.4	91.0	96.0	93.5	120.0	112.0	110.8	114.3
6	Clinton silt loam	22.7	28.0	106.8	97.4	102.8	102.3	105.3	104.0	106.8	105.3
7	Grundy silt loam	17.6	25.0	82.7	81.4	85.4	83.2	81.4	85.0	81.4	82.6

TABLE 4.—*The effect of air drying on the nitrifying power of soils when different amounts of ammonium sulfate are added, incubation period 15 days.*

Plat No.	Soil type	Moisture content		Nitrogen as nitrate in parts per million					
				Moist soil			Dry soil		
		In field %	Optimum %	No treatment	30 mgs. $(NH_4)_2SO_4$ added	100 mgs. $(NH_4)_2SO_4$ added	No treatment	30 mgs. $(NH_4)_2SO_4$ added	100 mgs. $(NH_4)_2SO_4$ added
912	Carrington loam	13.5	20.0	15.7	66.2	73.5	17.9	63.0	73.5
1000	Carrington loam	13.0	20.0	38.9	87.2	94.5	24.2	85.2	98.7
1430	Webster silt loam	22.0	27.0	27.3	95.5	252.0	32.5	76.6	252.0
1000	Carrington loam[a]	—	20.0	—	—	—	27.3	86.2	—

[a] Sample had been air dried in laboratory eight weeks.

In another investigation by one of the authors in which methods of taking field samples for nitrification tests were being studied, it was found that air drying had practically no effect on the nitrifying power of well-drained field soils if the physical condition of both the moist and the air-dried soils was kept the same during the incubation period. The importance of aeration, which has been pointed out by other investigators (1), (2), (8), (12), and (14) is a very significant factor in the nitrification process, and any comparison between moist and dry soils must be made in such a way that there will be no change in the structure of the moist soil after it has been air dried and remoistened. Since many soils take on a granular structure when air dried which leaves them very porous when placed in tumblers and moistened, the authors believe that this factor which causes better aeration has played an important part in showing a higher nitrifying power in some soils, while in others, which have been pulverized too fine, a lower nitrifying power may be evidenced due to the puddling effect which is produced when water is added to bring the soils up to the optimum moisture content.

The next experiment was conducted in order to determine the relation between the reaction of the soil and its nitrifying power (3). In a previous investigation by one of the authors (10) in which only a few soils were used, a very close agreement between these two factors was obtained. If this correlation would hold true for all soils, then their nitrifying power could be determined very quickly by making a soil acidity test. Forty-five soils were used in this study. They were secured from all parts of Iowa and since many of them were taken when the soil was practically air dry, it was decided to air dry all of the samples and pass them through a 20-mesh sieve so that after they were remoistened they would be similar in structure to that of moist soils brought from the field. Two different amounts of ammonium sulfate were used in studying the nitrifying power of these soils. One hundred milligrams per 100 grams of soil as recommended by Brown (6) and others were compared with 30 milligrams per 100 grams of soil which more nearly coincides with applications in the field. The smaller application does not seriously inhibit bacterial activities in sandy soils, and then too, the amount of nitrate produced can be very conveniently determined by the phenoldisulfonic acid method. The time of incubation was 15 days for the 30-milligram treatment and 28 days for the 100-milligram application. The method used was the same as that previously described. The results are given in Table 5.

The data from this experiment have been arranged according to

TABLE 5.—*The effect of soil reaction and time of incubation on the nitrification of ammonium sulfate when applied at the rate of 30 mgs. and 100 mgs. per 100 grams of soil and incubated at 25° to 27°C. at an optimum moisture content.*

Soil type	Source	Reaction¹		Total N in pounds per acre	Crop	Incubated 15 days		Original not incubated	Increase of NO_3		Incubated 28 days		Original not incubated	Increase of NO_3	
Loams, silt loams, and clay loams		Truog test	Comber test			30 mgs. $(NH_4)_2SO_4$ N as NO_3 p.p.m.	Control N as NO_3 p.p.m.	N as NO_3 p.p.m.	Soils own N N as NO_3 p.p.m.	N added N as NO_3 p.p.m.	100 mgs. $(NH_4)_2SO_4$ N as NO_3 p.p.m.	Control N as NO_3 p.p.m.	N as NO_3 p.p.m.	Soils own N N as NO_3 p.p.m.	N added N as NO_3 p.p.m.
Grundy silt loam	Henry Co.	st.	st.	4,290	Corn	113.4	51.5	27.0	24.5	61.9	248.0	87.8	27.0	60.8	160.2
Carrington loam	Story Co.	st.	st.	2,970	Oats	53.6	7.9	trace	7.9	45.7	114.5	27.6	trace	27.6	86.9
Carrington silt loam	Benton Co.	st.	st.	3,320	Corn	137.1	88.2	35.0	53.2	48.9	165.8	100.0	35.0	65.0	65.8
Muscatine silt loam	Scott Co.	st.	st.	4,060	Corn	136.0	76.4	10.0	66.4	59.6	174.2	95.7	10.0	85.7	78.5
Carrington loam	Bremer Co.	st.	st.	3,030	Corn	83.4	34.7	3.7	31.0	48.7	99.0	42.0	3.7	38.3	57.0
Waukesha silt loam	Benton Co.	st.	st.	4,350	Corn	134.0	65.2	18.0	47.2	68.8	200.0	72.4	18.0	54.4	127.6
Carrington silt loam	Linn Co.	st.	st.	4,060	Corn	110.6	55.1	11.0	44.1	55.5	147.9	76.6	11.0	65.6	71.3
Tama silt loam	Jasper Co.	m.+	m.	3,490	Corn	149.8	68.5	42.0	26.5	81.3	316.0	103.6	42.0	61.6	212.4
Clinton silt loam	Van Buren Co.	m.+	st.	2,980	Oats	97.8	45.6	trace	45.6	52.2	187.2	68.0	trace	68.0	119.2
Clinton silt loam	Des Moines Co.	m.+	st.	3,770	Onions	102.0	55.2	35.0	20.2	46.8	202.3	93.8	35.0	58.8	108.5
Muscatine silt loam	Louisa Co.	m.+	st.	4,520	Corn	140.0	65.4	12.5	52.9	74.6	197.2	86.9	12.5	74.4	110.3
Clyde silt loam	Benton Co.	m.+	m.	6,640	Corn	189.0	117.8	42.0	75.8	71.2	308.0	115.4	42.0	73.4	192.6
Carrington loam	Story Co.	m.	m.	3,600	Corn	68.3	26.7	8.5	18.2	41.6	213.0	56.0	8.5	47.5	157.0
Clarion loam	Story Co.	m.	m.	4,970	Clover	59.9	12.6	trace	12.6	47.3	231.0	37.6	trace	37.6	193.4
Grundy silt loam	Des Moines Co.	m.	m.	4,570	Corn	103.6	57.8	12.0	45.8	45.8	223.0	80.8	12.0	68.8	142.2
Bremer silt loam	Black Hawk Co.	m.	m.	4,230	Corn	134.0	49.4	37.5	11.9	84.6	286.0	63.8	37.5	26.3	222.2
Marshall silt loam	Woodbury Co.	sl.+	sl.	4,520	Corn	115.5	85.6	11.2	74.4	29.9	280.0	135.0	11.2	123.8	145.0
Carrington loam	Story Co.	sl.+	sl.	3,720	Corn	82.0	27.3	6.0	21.3	54.7	284.0	50.3	6.0	44.3	233.7
Marshall silt loam	Pottawattamie Co.	sl.	m.	4,120	Corn	186.2	94.3	11.5	82.8	91.9	258.0	107.8	11.5	96.3	150.2
Tama silt loam	Black Hawk Co.	sl.	n. a.	3,620	Corn	147.5	79.6	14.0	65.6	67.9	333.7	100.8	14.0	86.8	232.9
Peat	Buena Vista Co.	sl.	n. a.	14,600²	Corn	159.7	86.1	n. det.	——	73.6	633.0	135.0	n. det.	——	498.0
Peat	Story Co.	sl.	n. a.	19,450²	Corn	727.0	354.0	470.0	—116.0	373.0	1,118.0	575.0	470.0	105.0	543.0
Bremer silt loam	Louisa Co.	v. sl.	v. sl.	4,120	Corn	119.0	57.8	11.5	46.3	61.2	264.0	80.0	11.5	68.5	184.0
Wabash loam	Louisa Co.	n. a.	n. a.	2,980	Corn	87.3	37.1	12.3	24.8	50.2	347.0	63.0	12.3	50.7	284.0
Knox silt loam	Woodbury Co.	n. a	n. a.	2,970	———	81.5	48.2	8.0	40.2	33.3	306.0	86.9	8.0	78.9	219.1
Lamoure clay loam	Story Co.	n. a.	n. a.	7,740	Alfalfa	98.7	55.6	46.0	9.6	43.1	282.0	107.0	46.0	61.0	175.0
Webster silt loam	Story Co.	n. a.	n. a.	7,850	Clover	48.9	13.0	trace	13.0	35.9	227.6	34.1	trace	34.1	193.5
Sandy loams and sands															
Waukesha fine s'ndy l'm	Louisa Co.	st.	st.	2,340	Corn	56.0	43.4	5.8	37.6	12.6	92.0	42.0	5.8	36.2	50.0
O'Neill sandy loam	Black Hawk Co.	st.	st.	685	Corn	26.7	13.3	trace	13.3	13.4	22.6	28.7	trace	28.7	—6.1
Buncker coarse sand	Muscatine Co.	m.+	m.	1,430	Rye	34.5	6.2	trace	6.2	28.3	46.1	6.2	trace	6.2	39.9
Buckner coarse s'ndy l'm	Van Buren Co.	m.+	v. st.	2,800	Rye	29.7	6.3	trace	6.3	23.4	46.8	38.0	trace	38.0	8.8
Carrington sandy loam	Butler Co.	m.+	m.	1,830	Corn	50.9	19.1	trace	19.1	31.8	80.2	26.7	trace	26.7	53.5
Lindley fine s'ndy l'm	Linn Co.	m.+	m.	1,030	Corn	29.2	15.3	trace	15.3	13.9	none	20.5	trace	20.5	—20.5
Lindley sand	Story Co.	m.	m.	860	Corn	20.6	1.0	trace	1.0	19.6	52.4	13.6	trace	13.6	38.8
Lindley fine sandy loam	Story Co.	v. sl.	v. sl.	1,000	Corn	101.8	52.7	88.0	—35.3	49.1	322.4	90.3	88.0	2.3	232.1
Pierce sand	Story Co.	n. a.	n. a.	1,090	Melons	46.2	6.7	trace	6.7	39.5	241.0	19.4	trace	19.4	221.6

[1] st. =strong; m =medium; sl. =slight; n. a. =not acid, v. =very; n. det. =not determined.

[2] Nitrogen calculated per 1,000,000 pounds of soil.

TABLE 6.—*The effect of different fertilizer treatments on the nitrification of ammonium sulfate when applied to 100-gram portions of soil at the rate of 30 mgs. and 100 mgs. and incubated at 25° to 27° for 15 and 28 days.*

Plat No.	Soil type	Treatment[1]	Reaction[2]		Crop	Total N in pounds per acre	Incubated 15 days		Original not incubated	Increase of nitrate from		Incubated 28 days		Original not incubated	Increase of nitrate from	
			Truog test	Comber test[3]			30 mgs. $(NH_4)_2SO_4$ N as NO_3 p.p.m.	Control N as NO_3 p.p.m.	N as NO_3 p.p.m.	Soils own N N as NO_3 p.p.m.	N added N as NO_3 p.p.m.	100 mgs. $(NH_4)_2SO_4$ N as NO_3 p.p.m.	Control N as NO_3 p.p.m.	N as NO_3 p.p.m.	Soils own N N as NO_3 p.p.m.	N added N as NO_3 p.p.m.
912	Carrington loam	none	m.+	m.+	W. wh't	3,340	56.0	32.0	3.6	28.4	24.0	143.0	33.6	3.6	30.0	109.4
913	Carrington loam	M.	m.	m.+	W. wh't	3,360	70.0	36.0	6.0	30.0	34.0	172.0	54.7	6.0	48.7	117.3
914	Carrington loam	M, L.	sl.	v. sl.	W. wh't	——	115.0	35.0	6.0	29 0	80.0	260.0	54.7	6.0	48.7	205.3
916	Carrington loam	M, L, A. P.	sl.	v. sl.	W. wh't	——	112.0	46.0	10.4	35.6	66.0	286.0	54.7	10.4	44.3	231.3
1000	Carrington loam	none	st.	st.	Oats	4,280	115.0	31.0	2.6	28.4	84 0	193.0	42.0	2.6	39.4	151.0
1001	Carrington loam	M.	st.	st.	Oats	4,720	118.0	33.0	3.6	29.4	85.0	210.0	46.2	3.6	42.6	163.8
1002	Carrington loam	M, L	m.	sl.	Oats	4,130	120.0	60.0	0.6	59.4	60.0	277.0	46.2	0.6	45.6	230.8
1004	Carrington loam	M, L, A. P.	m.	sl.	Oats	4,740	114.0	32.0	0.4	31.6	82.0	311.0	44.1	0.4	43.7	266.9
1012	Carrington loam	none	st.	st.	Corn	3,960	104.0	28.0	0.8	27.2	76.0	147.0	33.6	0.8	32.8	118.4
1013	Carrington loam	M.	st.	st.	Corn	3,660	96.0	26.0	2.4	23.6	70.0	181.0	37.8	2.4	35.4	143.2
1014	Carrington loam	M, L.	v. sl.	v. sl.	Corn	——	120.0	30.0	1.2	28.8	90.0	269.0	58.8	1.2	57.6	210.2
1016	Carrington laom	M, L, A. P.	sl.	v. sl.	Corn	4,140	118.0	30.0	3.6	26.4	88.0	294.0	54.7	3.6	51.1	239.3
1100	Carrington loam	none	st.	st.	Oats	2,970	53.6	7.9	trace	7.9	45.7	114.5	27.6	trace	27.6	86.9
1101	Carrington loam	M.	st.	st.	Oats	2,670	57.8	15.1	trace	15.1	42.7	123.2	31.6	trace	31.6	91.6
1103	Carrington loam	M, L.	sl.	v. sl.	Oats	3,490	56.8	12.6	trace	12.6	44.2	249.0	35.5	trace	35.5	213.5
1106	Webster loam	M, L, R. P.	sl.	sl.	Oats	5,160	120.0	46.0	1.6	44.4	74.0	272.0	55.3	1.6	53.7	216.7
1110	Webster loam	none	sl.	v. sl.	Oats	6,040	136.0	48.0	3.0	45.0	88.0	281.0	61.6	3.0	58.6	219.4
1112	Webster loam	M, L, R. P. K.	n. a.	n. a.	Oats	6,760	122.0	40.0	1.0	39.0	82.0	276.0	53.2	1.0	52.2	222.8
1200	Carrington loam	none	n.	m.	Corn	3,600	68.3	26.7	8.5	24.2	41.6	213.0	56.0	8.5	47.5	157.0
1201	Carrington loam	M.	sl.	sl.	Corn	4,120	77.7	27.0	7.5	19.5	50.7	272.2	47.4	7.5	39.9	224.8
1203	Carrington loam	M, L.	n. a.	n. a.	Corn	3,770	80.0	30.5	8.5	22.0	49.5	284.0	52.5	8.5	44.0	231.5
1206	Webster loam	M, L.	n. a.	v. sl.	Corn	7,000	126.0	42.0	1.6	40.4	84.0	272.0	53.6	1.6	52.0	218.4
1210	Webster loam	none	n. a.	n. a.	Corn	7,320	120.0	40.0	5.0	35.0	80.0	255.0	48.9	5.0	43.9	206.1
1212	Webster loam	M, L, R. P. K.	n. a.	n. a.	Corn	8,600	140.0	55.0	3.2	51.8	85.0	276.0	66.0	3.2	62.8	210.0
1300	Carrington loam	none	sl.+	sl.	Corn	3,720	82.0	27.3	6.0	21.3	54.7	284.0	50.3	6.0	44.3	233.7
1301	Carrington loam	M.	v. sl.	n. a.	Corn	4,400	81.4	31.5	30.0	1.5	49.9	277.0	63.2	30.0	33.2	213.8
1303	Carrington loam	M, L.	v. sl.	n. a.	Corn	4,460	71.5	35.7	30.0	5.7	35.8	269.0	61.2	30.0	31.2	207.8
1400	Clarion loam	none	m.	m.	Clover	4,970	59.9	12.6	trace	12.6	47.3	231.0	37.6	trace	37.6	193.4
1401	Clarion loam	M.	m.	m.	Clover	4,400	58.8	13.0	trace	13.0	45.8	206.0	35.5	trace	35.6	170.5
1403	Clarion loam	M, L.	v. sl.	n. a.	Clover	4,800	55.1	9.5	trace	9.5	45.6	213.5	29.6	trace	29.6	183.9
1430	Webster clay loam	none	n. a.	n. a.	Clover	7,850	48.9	13.0	trace	13.0	35.9	227.6	34.1	trace	34.1	193.5
1431	Webster clay loam	C. R., A. P.	n. a.	n. a.	Clover	8.130	51.0	15.1	trace	15.1	35.9	221.6	40.3	trace	40.3	181.3
1	Muscatine silt loam	none	st.	st.	Oats	4,960	172.0	58.0	2.2	55.8	114.0	200.0	76.6	2.2	74.4	123.4
3	Muscatine silt loam	M, L.	sl.	sl.	Oats	5,100	172.0	82.0	1.2	80.8	90.0	327.0	83.0	1.2	81.8	244.0
5	Muscatine silt loam	M, L, A. P.	sl.	sl.	Oats	4,780	180.0	66.0	2.0	64.0	114.0	323.0	91.5	2.0	89.5	231.5
1	Grundy silt loam	none	st.	st.	Corn	3,700	110.0	34.0	2.0	32.0	76.0	170.0	51.0	2.0	49.0	119.0
3	Grundy silt loam	M, L.	sl.	m.	Corn	4,200	110.0	44.0	4.8	39.2	66.0	285.0	59.6	4.8	54.8	225.4
5	Grundy silt loam	M, L, A. P.	v. sl.	v. sl.	Corn	3,600	112.0	43.0	1.4	41.6	69.0	281.0	49.0	1.4	47.6	232.0
1	Marion silt loam	none	m.	st.	Corn	2,920	152.0	86.0	22.8	63.2	66.0	196.0	123.0	22.8	100.2	73.0
3	Marion silt loam	M, L.	n. a.	n. a.	Corn	2,920	176.0	86.0	13.2	72.8	90.0	340.0	95.8	13.2	82.6	244.2
5	Marion silt loam	M, L, A. P.	v. sl.	v. sl.	Corn	3,060	164.0	88.0	18.6	69.6	76.0	361.0	87.2	18.6	68.6	273.8

[1] M = manure; L = lime; A. P. = acid phosphate; R. P. = rock phosphate; K = potassium chloride; C. R. = crop residues.

[2] n. a. = not acid; v. = very; sl. = slight; m. = medium; st. = strong.

[3] Modified thiocyanate test.

the texture of the soils and also according to the acidity as determined by the Truog (17) test. These soils were also tested for acidity by the modified Comber (9) thiocyanate test, and very good agreement between the two tests was obtained.

If the data given in Table 5 were plotted to show the relation between degree of acidity and the amount of nitrate produced from the 100-milligram treatment of ammonium sulfate, it would be found that in most cases as the degree of acidity increased the nitrifying power decreased. There are some exceptions, however, as soils No. 1 and No. 8 have a higher nitrifying power than soils No. 17 and 19 which are much less acid. It is not impossible that the degree of aeration may have been partly responsible for this variation, since soils Nos. 17 and 19 were low in organic matter and were very easily compacted while the opposite was true of soils No. 1 and No. 8.

However, when the lighter application of ammonium sulfate was studied, it was found that there was no correlation between the nitrifying power of these soils and their reaction. The nitrifying power of the acid soils was just as vigorous as that of the neutral or basic soils except in the case of a peat (No. 41) in which the microorganisms seemed to be stimulated by the addition of the ammonium sulfate and produced a much larger amount of nitrate nitrogen than was added. This condition occurred in some of the other soils to a lesser extent with both the 30-milligram and 100-milligram treatments.

The advantages of the smaller amounts of ammonium sulfate and a shorter incubation period, as compared with larger amounts and a long incubation period, can be stated as follows: The smaller amounts of nitrate produced in the short incubation period can be measured more easily and more accurately, using the phenoldisulfonic acid method, than the larger amounts produced in a long incubation period. More accurate information with reference to the activities of the nitrifying organisms in a soil can be secured by using the shorter incubation period because in the longer incubation the efficiency of the nitrifying bacteria is often masked in acid soils due to unfavorable conditions which may be produced as a result of increases in the hydrogen-ion concentration of the soil solution which retard the activities of the organisms. Also, in case of some sandy soils large amounts of ammonium sulfate depress nitrification while smaller amounts are readily nitrified. In neutral or basic soils an increase in vigor of the nitrifying organisms undoubtedly occurs in some instances due to the long incubation period under favorable conditions of soil reaction, temperature, moisture, and easily nitrifiable material. This is apparent from some of the results with slightly acid and neutral soils which are given in Table 5.

In the last experiment a study was made of the effect of fertilizer treatment and cropping on the nitrifying power of several soils secured from the agronomy farm and from some of the cooperative soil experiment fields in Iowa. The results of this experiment are given in Table 6.

The chief differences which are apparent from the data given in Table 6 are that the addition of limestone to the acid soils caused a marked increase in the nitrification of the ammonium sulfate added, with the exception of plats 1000, 1001, and 1016 which were in alfalfa for five years in a five year rotation. Two crops of corn and oats and one crop of wheat and clover have been removed from plats 1000 and 1001 since they were in alfalfa and only one crop of corn has been removed from plat 1016 Although the soil in these plats is strongly acid the 30-milligram application of ammonium sulfate was nitrified just as readily as in adjacent plats which have been treated with limestone and acid phosphate Other check plats in the same rotation which have not grown alfalfa but have grown the other crops do not contain vigorous nitrifying bacteria, consequently the effect of the alfalfa seems to be the factor which has stimulated the nitrifying bacteria in this soil When the 100-milligram application of ammonium sulfate was made to this soil and incubated 28 days, a much larger amount of nitrate was formed in the soils which had been limed. This is due no doubt to the unfavorable conditions which prevailed in the unlimed soils due to an increase in the hydrogen-ion concentration of the soil solution which retarded the action of the nitrifying bacteria.

Although in some instances (3), (19) the addition of phosphate to soils has increased their nitrifying power, in this experiment no significant increases were obtained due to the application of acid and rock phosphate to field plats. Several of these soils respond to phosphorus fertilizers when they are applied to winter wheat and to red clover and sometimes when they are used on corn and oats. It is evident from these data that the nitrifying power of the soil cannot be used to determine whether or not phosphate fertilizers should be applied for the best growth of general farm crops.

SUMMARY

A study was made of the nitrification of ammonium sulfate in a number of soils and of various factors which may affect the activity of the nitrifying organisms.

Air drying soils did not seem to affect the nitrification of ammonium sulfate if the same physical condition was secured after the soils were remoistened as that in the moist soil.

A higher percentage of nitrate nitrogen was produced from the smaller amounts of ammonium sulfate than was obtained from the larger applications.

In most cases a fairly good agreement occurred between the soil reaction and its nitrifying power when 100 milligrams of ammonium sulfate were added to 100 grams of soil and incubated for 28 days.

When 30 milligrams of ammonium sulfate were used in place of 100 milligrams and incubated with 100 grams of soil for 15 days, it was found that the nitrifying power of the acid soils used in this investigation was as great as that of the neutral or basic soils tested, and no correlation existed between nitrifying power and soil reaction.

Phosphorus and potash fertilization did not produce any significant increases in the nitrifying power of these soils over that produced by the addition of ground limestone. Since the yields of crops on many of these soils is increased by phosphorus fertilization, tests of the nitrifying power of soils cannot be used to determine the need of phosphates for general farm crops.

The residual effect of alfalfa on the nitrifying power of a Carrington loam was studied. Although some plats were strongly acid and had received no treatment, while others had received manure, limestone, and acid phosphate in different combinations, there was no difference in the rate at which a 30-milligram addition of ammonium sulfate was nitrified. Other check plats which had not grown alfalfa had a very low nitrifying power.

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5. THE NITRATE CONTENT OF THE RHODE ISLAND EXPERIMENTAL PLATS AS INFLUENCED BY FERTILIZERS AND CROPS[1]

JOHN B. SMITH[2]

A general survey of the accumulation of nitric nitrogen in the surface soils at this station has been made for the growing season of 1925, the survey having for its object a study of the magnitudes involved rather than the operation of single factors in effecting the changes. The results reported are from permanent plats and represent the cumulative effect of many years for each treatment. Since seasonal variations may to a large extent determine the activity of soil micro-organisms, no conclusions have been drawn from the results of a single year; but it is possible that the season may have a greater effect upon magnitudes attained than upon the normal course of the action, and this work may have interest from that point of view.

[1] Paper read as a part of the symposium on "Soil Bacteriology—Nitrification Studies" at the meeting of the Society held in Chicago, Ill., November 17, 1925. Contribution 324 of the Rhode Island Agricultural Experiment Station. Kingston, R. I. The writer wishes to extend thanks to Dr. Burt L. Hartwell and to Dr. Basil E. Gilbert for advice and council in this work, also to Mr. Waldo L. Adams for assistance with some of the determinations.

[2] Associate Chemist.

The soil was classified in 1913 by the U. S. Department of Agriculture as Merrimac silt loam, mellow and friable at the surface and underlain by a plastic, yellow silt loam. This plastic layer is a beneficial factor in preventing leaching from the surface into a substratum of coarse gravel. The natural acid reaction has been modified by liming so that the pH now ranges from 4.5 to 7.0, the areas studied falling between 5.5 and 7.0 unless otherwise stated.

In sampling, twelve 7-inch borings were composited from each thirtieth-acre plat and proportionately larger numbers from each larger plat. Nitric nitrogen was determined by the phenoldisulphonic acid method within 24 hours after sampling and results are reported as parts per million of dry soil. Until plants were of sufficient size to affect materially nitrate accumulations, borings were taken between the rows of drilled crops; afterward, directly in the row to obtain the maximum crop effect. Fertilizer applications are reported on an acre basis.

Although few analyses from preceding years are available for comparison, the season studied is believed to have been decidedly favorable for nitrate production and accumulation. Frequent small rains maintained a very uniform soil moisture with little evidence of serious leaching until near the end of the growing season. A rain of 1.24 inches for a week early in April appeared to remove considerable amounts of nitrate from the surface soil as did 2.08 inches on August 1, but these losses were rapidly replaced, either by further nitrification or by the return of nitrate from lower depths, following surface evaporation of soil water. Other rains, nearly as large, brought no observed change, probably finding the soil in a drier state. While no representative fallows were available late in the season, results from fallow in cylinders, referred to later, indicate a decided loss of nitrates from 3.91 inches of rain in September and 1.72 inches upon October 3, 4, and 5. Leaching rains show a decided tendency to reduce all nitrate accumulations in the surface soil to the same level, causing the greatest disappearance where previously the nitrates were highest. Moistures were higher following 32 tons of stable manure than with 16 tons; and the latter application, in turn, resulted in higher moisture percentages than when no manure had been used. The curve for green-manured soils was intermediate, following most closely that of the 16 tons of manure.

Temperatures taken between 7 and 8 A. M. to a soil depth of 3 inches rose rapidly from 45°F. on May 1 to 65° a month later and dropped very little from this level before the first of August, after which date there was an increasingly rapid decline to 40°F. on October 14. Temperatures at the same depth taken at 5 P. M. were approximately 10° higher.

Upon three plats treated alike but for the applications of lime, there was maintained a nitrate level, in fallow until June 8 and under oats thereafter, approximately 20 p.p.m. higher at a pH of 6.5 than at 4.8. Further liming to a 6.8 pH did not increase nitrate accumulation. The maximum nitrate content observed for these three plats was 56 p.p.m. upon June 7 at a pH of 6.5 and just before the growth period of a crop of oats. However, a maximum of 40 p.p.m. for the most acid plat indicates a very satisfactory nitrification at a pH of 4.8 and upon a plat that is not known ever to have had lime. The fertilizer application was equivalent to 1,500 pounds of a 6-6-8 ratio, two-fifths of the 75 pounds of nitrogen in nitrate of soda and three-fifths in sulfate of ammonia.

In Table 1 are reported data from the thirty-fourth year of a comparison of equal amounts of nitrogen in nitrate of soda and in sulfate of ammonia on Plats 23, 25, 27, and 29. Since the beginning, each of four plats has received 1,640 pounds of nitrogen, two of the plats in nitrate of soda and two in sulfate of ammonia. The comparison this year was made at two degrees of acidity, one nitrate of soda plat never having had lime, one sulfate of ammonia plat having had barely enough lime to allow for feeble growth of acid-sensitive crops, and the remaining two having been brought to approximately 5.5 pH. The nitrogen was added in two equal applications, each equivalent to 1,500 pounds of a 5 8-8 fertilizer, one application on April 2, the other on July 17, both together carrying 120 pounds of nitrogen. For this one season the sulfate of ammonia has proved equal to the nitrate of soda for nitrate production at a pH of 5.5, as the early advantage of nitrate of soda was overcome by the middle of June and the lead held by sulfate of ammonia thereafter. At the above reaction the peak of the observed nitrate of soda curve for nitrate accumulation was at 70 p.p.m. on May 21, followed by a decided downward trend, continuing even after the midsummer fertilization, 22 p.p.m. disappearing between July 30 and August 12. This last removal cannot be accounted for entirely by the leaching rain of August 1, for in the same period the three other plats were consistent in losing less than half this amount. This, added to the losses for the same plat between May 21 and July 13, and compared with nearly equal gains in that period for the unlimed nitrate of soda plat, indicates a possible assimilation of nitrates by some form of soil organism, stimulated to activity at a pH of 5.5 but held in check at 4.7. If this be true, the less acid sulfate of ammonia treatment must also have

TABLE 1.—*Nitrate of soda versus sulfate of ammonia for nitrate production.*

			NO$_3$ nitrogen in fallow soil expressed in p.p.m. of dry soil											
Plat No.	60 pounds of nitrogen per acre in[a]	April 17 pH	April 6	April 14	April 17	April 22	April 27	May 4	May 21	June 8	July 13	July 30	Aug. 12	Oct. 7
23	Sulfate of ammonia	4.5				10			26	34	44	52	42	42[b]
27	Nitrate of soda	4.7				17			38	42	62	74	64	14[b]
25	Sulfate of ammonia	5.5	8	19	17		21	26	46	36	48	74	62	4[b]
29	Nitrate of soda	5.6	30	38	26		24	30	70	40	38	68	46	2[b]

[a] A second 60 pounds of nitrogen was added on July 17.

[b] One month after harvest of a crop of spinach on another area of plat. No growth on Plat 23.

restrained such action for here the gains show progressive accumulation of nitric nitrogen. This progressive curve was followed very closely by that for the unlimed nitrate of soda. Lime improved the nitrification of sulfate of ammonia, yet the more acid area did not fall below 25 p.p.m. after May 21, and reached an observed maximum of 52 p.p.m., sufficient nitrate to indicate that lack of available nitrogen is not the limiting factor for crop growth on this area.

A study was made of a series of plats treated with 8, 16, and 32 tons of stable manure and added chemicals. Data were taken under fallow conditions in early spring and in midsummer, under spinach following the spring fallow, and under carrots in the late summer. This manure was assembled during the preceding winter and contained straw bedding. The chemical fertilizer carried liberal amounts of phosphoric acid and potash, and quantities of nitrogen varying from 84 to 150 pounds per acre for the season. In general, it may be stated that increasing the manure application did not increase nitrate accumulation where chemical applications were the same, but that an increase in fertilizer nitrogen resulted in a higher level, both under fallow conditions and on areas cropped with spinach and carrots. Doubling the 180-pound application of phosphoric acid did not increase nitrification. On two plats following the plowing in of a good stand of ryegrass and clover, and the addition of two applications of fertilizer carrying 150 pounds of nitrogen for the season, 8 tons of manure produced decidedly greater magnitudes of nitric nitrogen than did 16 tons.

It is interesting to compare the application of 16 tons of manure and 70 pounds of fertilizer nitrogen (30 pounds in nitrate of soda, 25 pounds in sulfate of ammonia, and 15 pounds in tankage) with the nitrate of soda and sulfate of ammonia treatments mentioned previously. As a crop of spinach was beginning growth late in May, 60 pounds of nitrogen in nitrate of soda presented to the crop 70 p.p.m. of nitric nitrogen, an equal amount of nitrogen in sulfate of ammonia, 46 p.p.m., while the 70 pounds of fertilizer nitrogen used with 16 tons of manure had accumulated but 26 p.p.m.

A further comparison is between manure alone and chemicals alone. One plat has received 22 annual applications of 10 cords of manure, while another has had liberal chemical fertilizers for an equal period and a considerable quantity of green manure. Data for the 1925 season are given in Table 2. At the sampling dates, there was more nitrate under the cabbages on the chemical plat than on the manure plat, where the nitrate level was decidedly low. Yet a somewhat better growth was made with the manure than with the chemicals, and the nitrogen in the dry matter of the crop was 2.20% in the first case as compared with 2.26% in the second. If the nitrogen in the crop was absorbed as nitrate, it is evident that the manure produced a constant supply of nitric nitrogen as it was needed by the crop, and equal in total amount to the chemical plat, but did not accumulate quantities in excess of crop needs. It may be due to the observed 3% difference in moisture in favor of the manure treatment that growth was slightly better. From the standpoint of nitrification, manure alone, or used with chemical nitrogen, has acted as a stabilizer, preventing rapid early accumulation of nitrates, but extending the effect over the season.

TABLE 2.—*Manure versus chemicals.*

NO_3 nitrogen expressed in p.p.m. of dry soil

	Cabbage					Rye	
	June 24	July 6	July 22	July 30	August 26	Sept. 30	Oct. 7
10 cords manure	6	8	**4**[a]	**3**	**2**	**8**	**4**
Green manure, June 12 120 pounds N, June 16	38	40	**20**	**18**	**2**	**13**	**4**

[a]Bold face indicates areas under influence of crop. Fifteen pounds of N in nitrate of soda added September 15 after harvest of cabbage and before rye.

A rotation for market garden crops, planned to compare green manures plus chemicals with 16 tons of stable manure plus chemicals and with 32 tons of stable manure without chemicals, was studied while in preparation for celery and under that crop. Results are tabulated in Table 3.

Both applications of stable manure were made in the spring, the plat receiving 16 tons being given also the equivalent of 1,500 pounds of 4–11–0 fertilizer. After removing the preceding crop, lettuce, the equivalent of 1,200 pounds of 5–8–8 fertilizer was disked and harrowed into this plat on July 7, a third plat receiving one-half more nitrogen than the regular treatment at each application. On another series of plats good stands of three cover crops, *viz.*, timothy, rye, and oats were plowed and disked in on June 12, May 20, and June 1, respectively, all at succulent stages of growth. These crops had been well fed with nitrogen, and contained at the time of plowing the following percentages of nitrogen in dry matter: Timothy, 1.20%; rye, 1.60%; and oats, 3.30%. The equivalent of 2,500 pounds per acre of 4–8–6 fertilizer was harrowed in just before setting celery on July 10, a second oat plat being given an extra half ration of nitrogen. As may be noted in the table, the extra nitrogen plat with the stable manure had about the same amount of fertilizer nitrogen as did the regular green manure treatment. The celery was slow in starting and it was

TABLE 3.—*Stable manure, green manure, and chemicals for celery*

Treatment[a]	Pounds of nitrogen added in chemicals	NO$_3$ nitrogen expressed in p.p m. of dry soil May 14	June 1	June 8	June 24	July 6	July 22	Aug 4	Aug. 17	Sept 10	Sept. 22	Oct. 9
32 T. M	0						**30**	**14**	**24**	**18**	**15**	**10**
16 T. M.+Ch	50						**52**	**36**	**46**	**18**	**15**	**8**
16 T. M.+Ch. (Ext. N)	75						**68**	**34**	**48**	**20**	**15**	**17**
Green manures												
Timothy +Ch	80				3	6	**40**	**34**	**44**	**26**	**8**	**5**
Rye +Ch	80	**T**[b]	4	8	24	20	**66**	**36**	**48**	**56**	**11**	**T**
Oats +Ch. first plat	80					48	**72**	**60**	**70**	**30**	**16**	**5**
Oats +Ch. second plat	80		**48**		14	46	**86**					
Oats +Ch.+8 T. M	80					42	**92**	**36**	**54**	**50**	**14**	**7**
Oats +Ch. (Ext. N)	120					64	**148**	**50**	**62**	**92**	**32**	**5**

[a] T. M. = tons stable manure; Ch. = chemicals; Ext. N = extra half ration of N; T = trace.

[b] Boldface indicates determinations under growing crops

not until after July 22 that evidence of crop effect upon nitrate accumulation was noted. Differences after this date were undoubtedly masked by crop absorption but, summarized briefly from the standpoint of nitrate levels maintained under a somewhat uniform crop growth, the data indicate that:

1. Thirty-two tons of manure alone are not equal to 16 tons of manure with chemicals.
2. Differences between 75 and 50 pounds of fertilizer nitrogen with 16 tons of stable manure were masked by the growing crop.
3. Oat, rye, and timothy green manures plowed in with a uniform application of fertilizer nitrogen presented nitric nitrogen to the crop in relation to the percentage of nitrogen in the green manure dry matter, the highest nitrogen percentage producing the most nitrate.
4. All but the timothy plat contained more nitric nitrogen at the beginning of crop growth than could be accounted for by the fertilizer nitrogen added, assuming a 6- to 7-inch layer of soil to weigh 2,000,000 pounds.
5. Under the conditions of this experiment, timothy and rye green manures with 80 pounds of fertilizer nitrogen were fully equal in production of nitrate to the 16 tons of manure with chemicals. Oat green manure with 3.30% of nitrogen in dry matter was superior.
6. Eight tons of stable manure added to the oat green manure and fertilizer produced a higher initial nitrate content but did not maintain this lead under the crop.
7. The additional half ration of nitrogen added to the regular oat green manure and chemicals brought the highest observed accumulation of the season, 148 p.p.m. on July 22, and maintained the highest level under the celery.
8. No correlation was found between nitrate level and crop growth.

In all cases observed, the curve of nitrate accumulation for cropped areas declined rapidly, and especially was this true late in the season. A decline was anticipated and an attempt was made to compare fallow and cropped conditions by driving four cylinders into each of certain plats before growth began. The cylinders, 6 inches long and 8 inches in diameter, were driven in even with the surface and sampled in pairs upon the same dates that areas under the crops were taken. Agreement between the pairs was sufficiently close, both for nitric nitrogen and moisture; also, there was little difference, as shown by analysis, for total nitrogen and moisture between the cylinders and cropped areas. When three sets of curves were drawn representing averages for as many sets of plats, it was found that the nitrate-accumulation curve for the fallow cylinders followed that for the cropped area, although at a higher level, but that both ended at very low points, indicating almost complete depletion of nitric nitrogen supplies before harvest. A single plat, furnished with cylinders 18 inches long and 1 foot in diameter, gave a curve very similar to the average, tending to show that the length of the small cylinders was sufficient. Frequent rains toward the end of the season and cooler soil temperature might account for much of this apparent loss from fallows, but the possibilities of diffusion from the cylinders, of root effects below the 6-inch levels, and of varying water movements due to broken capillary columns in the cylinders make it impossible to draw definite conclusions.

Observations were made upon the rate of nitrate absorption by different species of plants. On an area of uniform fertilization, nitrate determinations on July 30 under maturing crops of onions, mangels, carrots, and cabbages show that the leafy cabbages and mangels had absorbed all but 5 p.p.m. of nitric nitrogen, while under the carrots and onions there remained 65 p.p.m. Again, samples were taken on August 17 under three crops growing on the same plat. Mature cabbages had taken all but 8 p.p.m. of nitric nitrogen, maturing peppers had 17 p.p.m. remaining, while half-grown eggplant had 44 p.p.m.

Little can be said with regard to correlation of nitrate content of field soils found in this work and the yields of crops. Extra applications of nitrogen did not increase the yield of the two crops studied most carefully, carrots and celery, hence it seems probable that the levels reported for the regular treatments of those crops may be considered sufficiently high.

6. AMMONIA AND NITRATE STUDIES OF LAKES NEAR MADISON, WISCONSIN[1]

B. P. DOMOGALLA AND E. B. FRED[2]

This paper deals with the biochemical changes taking place in the chain of lakes situated in the vicinity of Madison, Wisconsin. Special attention has been given to the fluctuations that take place in these lakes and to the factors that influence these changes, e.g., stratification, temperature, light, oxygen supply, and agricultural and industrial nature of the watershed, as well as inflowing drainage and ground waters.

PROCEDURE

LAKES STUDIED

The chain of lakes, including Mendota, Monona, Waubesa, Kegonsa, and Wingra, is situated in the Yahara River basin. (See Fig. 1.) A detailed description of these lakes and their plant and animal life has been given in reports of the Wisconsin Geological and Natural History Survey (1, 2)[3], hence only a brief statement will be given in this paper.

These lakes are comparatively small, the area of the largest being approximately 40 sq. km. (15 sq. mi.) They are not very deep, the maximum being about 26 m. (84 ft.). The areas, volumes, and the maximum and mean depths, as well as the average drop between these lakes, are shown in Table 1. They are glacial hard water lakes, placed in drift basins, and are fed from the ground waters and small affluents. The shores of Lake Mendota, which is the largest lake in this chain, are for the most part high and have a steep slope. Lake Wingra, in contrast, is a small shallow body of water and enters Lake Monona through Murphy Creek. Nearly the entire margin of this lake is swampy and marshy. A luxuriant growth of vegetation along this low margin feeds upon the high nitrates and other food constituents that enter this lake by means of springs and creeks. The conditions of the other three lakes, Monona, Waubesa, and Kegonsa, are more ordinary and lie between these two extremes. All of these lakes are covered with ice during several months of the winter. During the summer months the surface temperature reaches a maximum of 25° to 28°C.

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[1] Paper read as part of the symposium on "Soil Bacteriology—Nitrification Studies" at the meeting of the Society held in Chicago, Ill., November 17, 1925. This work was supported by the special research fund of the University of Wisconsin and the Engineering Department of the City of Madison, Wisconsin.

[2] City Biochemist, Madison, Wisc., and Professor of Agricultural Bacteriology, University of Wisconsin, respectively.

[3] Reference by number is to "Literature Cited," p. 910.

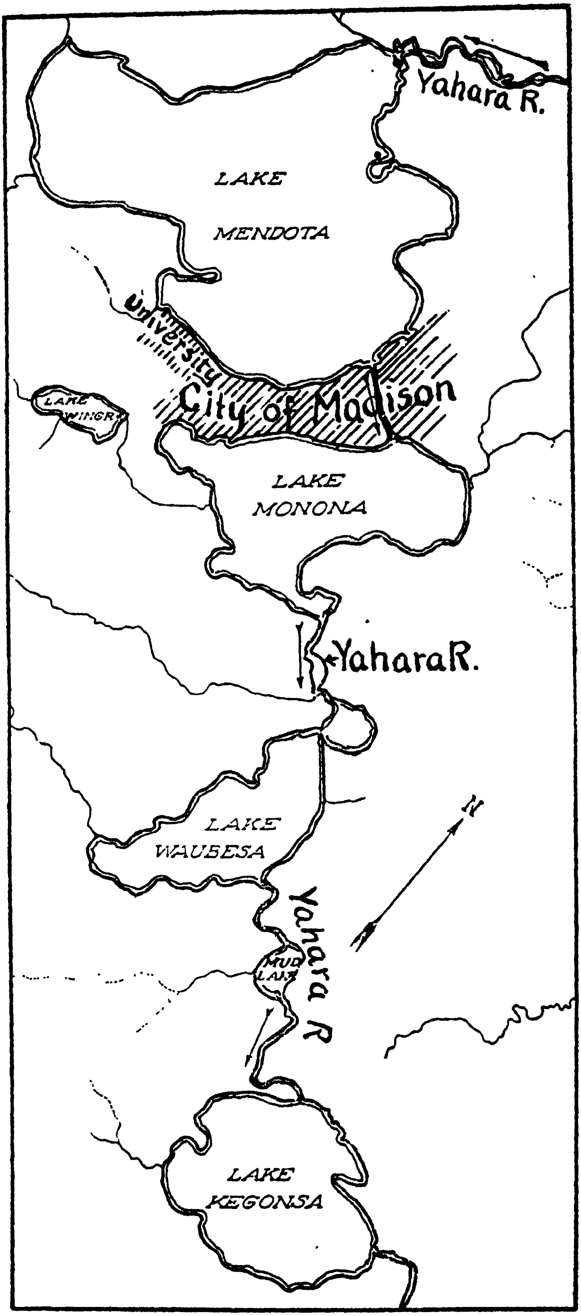


Fig. 1—Map of the chain of lakes, Madison, Wisc.

The cycle of the seasons induces a corresponding cycle of physicochemical changes known as seasonal stratification of the water. In spring when the ice disappears complete circulation of the lake water takes place. As the season advances the temperature of the water rises and the complete circulation is terminated by the rapid warming of the upper water which the wind can no longer force down and mix with the colder and heavier bottom water. The lake remains stratified until fall when the surface water cools. As soon as the upper water is about the temperature of that of the bottom strata turnover takes place caused by the wind and convection currents. Complete circulation of the entire water continues until winter stratification begins, then the lake freezes over and remains until the spring turnover. Previous investigations have shown that the waters of Lakes Mendota and Monona show a marked seasonal stratification, physically, chemically, and biologically (3). Lakes Waubesa, Kegonsa, and Wingra are so shallow that the water is not permanently stratified during the summer. This paper will discuss the conditions of the surface waters of the chain of lakes and refer to the bottom waters in so far as they affect the composition of the surface waters during the turnover period.

TABLE 1.—*Data on the chain of lakes about Madison, Wisconsin.*

Lake	Length	Width	Area	Maximum depth	Mean depth	Volume	Average drop between lakes
	Km.	*Km.*	*Sq. Km.*	*Meters*	*Meters*	*Cubic meters*	*Inches*
Mendota	9.50	7.40	39.40	25.6	12.1	478,370,000	—
Monona	6.70	3.85	14.10	22.5	8.4	118,887,000	36.0
Waubesa	6.75	2.25	8.24	11.1	4.9	40,252,000	3.4
Kegonsa	4.83	3.62	12.70	9.6	4.6	59,060,000	18.0
Wingra	1.60	0.60	—	4.3	2.7	5,600,000	—

SAMPLES

For chemical analyses, surface and bottom samples of 2 to 5 liters were taken from the middle of each lake every two weeks. For bacteriological tests special samples were collected at the same time in sterilized evacuated Pyrex test tubes. These samples were drawn by means of a bacteriological sampler (4).

METHODS OF ANALYSIS

The different forms of nitrogen were determined on fresh water according to the procedures given by the American Public Health Association (5). The soluble phosphate phosphorus was determined directly on the fresh water according to Atkins' method (6). This is a very sensitive and rapid method, and one can easily determine an amount as low as 0.001 mg. of phosphorus in 100 cc. of water.

TABLE 2.—*Organic nitrogen in 1 cubic meter of water from the several lakes.*

Date	Mendota	Monona	Waubesa	Kegonsa	Wingra
1925	*Mg.*	*Mg.*	*Mg.*	*Mg.*	*Mg.*
March 16	1,055	1,065	1,130		
April 6–25	1,040	1,050	1,100	1,060	752
May 1–9	860	972	980	974	832
June 6–8	800	952	984	975	790
July 7–13	832	896	1,080	1,060	830
July 24–28	840	880	1,100	1,090	835
Aug. 7–12	855	870	1,320	1,100	848
Aug. 17–19	865	885	1,470	1,200	855
Sept. 8–17	850	890	1,050	990	800
Oct. 1	855	895	990	950	——
Oct. 3–5	880	925	1,010	970	600
Nov. 20–26	860	935	1,025	1,000	670
Dec. 5–10	850	950	1,050	1,010	640

The rate of nitrification was measured by the time required for the oxidation of an ammonium sulfate solution, and the rate of reduction by the time required to destroy nitrates in the Giltay medium.

EXPERIMENTAL

I. CHEMICAL AND BACTERIOLOGICAL VARIATIONS IN A CHAIN OF LAKES

The data presented in the following tables show the variations that occur in different forms of nitrogen and phosphorus during the growing season. These data were obtained from March to October when all forms of life, especially the algae and weeds, are most active, feeding upon the various food constituents found in the waters. The conditions during this part of the year are similar to those in soils in that a crop is grown in the lake. The chief sources of nitrogen and phosphorus are from the inflowing waters as well as from the decomposition of the organic material contained in the mud and debris at the bottom of the lake. During the spring and fall turnovers the accumulated forms of soluble nitrogen in the lower strata are mixed with the surface waters and thus increase the surface food supply as was pointed out in a previous paper (7).

ORGANIC NITROGEN IN A CHAIN OF LAKES

Table 2 shows the total amount of organic nitrogen in the surface water, including both the soluble and insoluble organic nitrogen. The organic nitrogen in Lake Waubesa was at all times higher than that in the other lakes. Microscopical examinations showed that Waubesa had the largest amount of algae growing in its waters. At the time when the algae and weeds are most abundant, in August, the organic nitrogen reached its maximum. Similar observations on the other lakes showed a rise in the total organic nitrogen as soon as the plank-

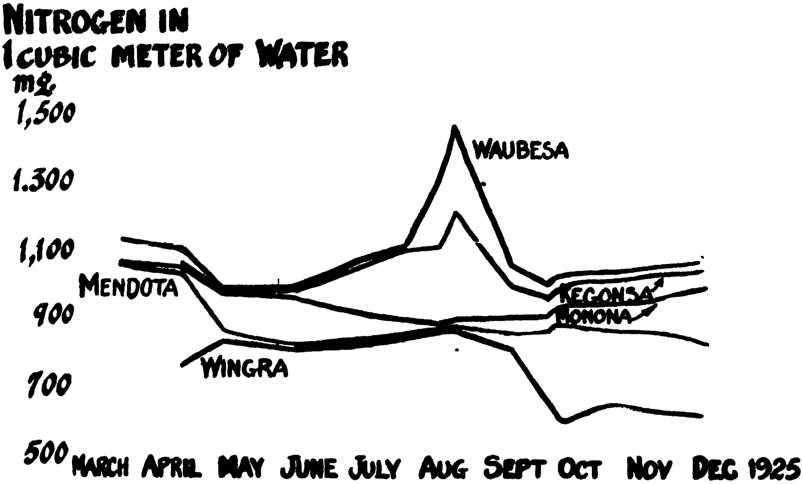


FIG. 2-ORGANIC NITROGEN IN LAKE WATER

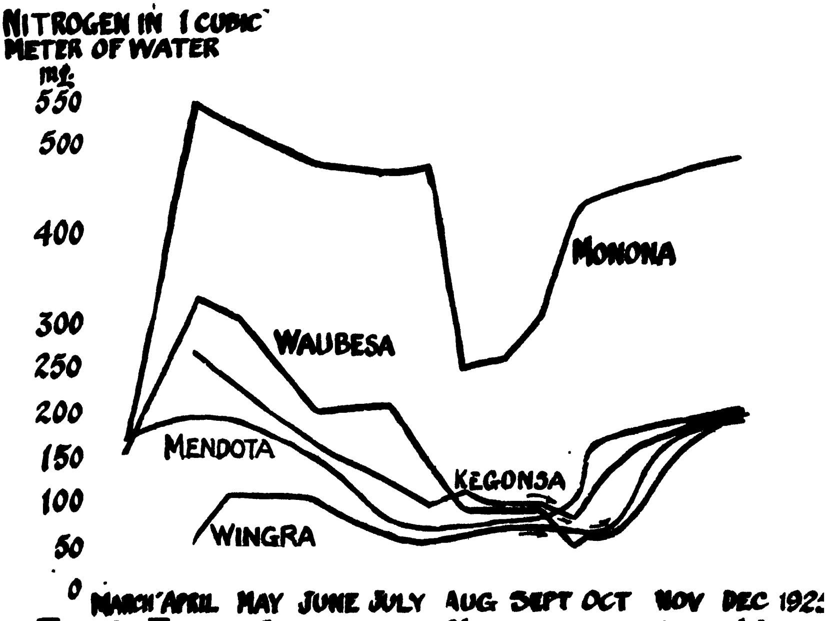


FIG. 3-FREE AMMONIA NITROGEN IN LAKE WATER

ton increased. At all times Mendota water showed less organic nitrogen as well as a lower content of plankton life than that found in Monona, Waubesa, and Kegonsa. Lake Wingra contained the smallest amount of organic nitrogen, even less than that of Mendota which had the lowest plankton content. This unusual condition of Lake Wingra may be accounted for in part by the small amount of organic nitrogen which flows into this lake, Lake Wingra being fed chiefly by springs. This lake is also small and is not stirred very much by the wind. The insoluble organic material therefore tends to settle to the bottom.

In March, just before the ice disappeared, the lakes showed a high amount of organic nitrogen which accumulated during the winter months. This, no doubt, is due to the low plankton growth and to an increase in the decompcsition of the material from the bottom mud. In a previous investigation (8) the soluble organic nitrogen in lake waters, especially in Lake Mendota, was shown to consist of proteins, peptides, and amino acids. Important amino acids, such as tryptophane, cystine, tyrosine, histidine, and arginine, were found in the soluble organic nitrogen. Nitrification proceeds in the presence of considerable soluble organic matter in these lakes. If the nitrifying bacteria are the same species as those found in soils, then it would seem that these soluble forms of nitrogen in soils would be beneficial.

FREE AMMONIA NITROGEN

Table 3 gives the results of the ammonia determinations. This form of nitrogen showed an increase in all the lakes during March and April. As soon as the plant and animal life, the plankton, of the lake increased in number the ammonia content dropped. Apparently some of these forms of life feed upon ammonia. The free ammonia

TABLE 3.—*Ammonia nitrogen in 1 cubic meter of water from the several lakes.*

Date 1925	Mendota *Mg.*	Monona *Mg.*	Waubesa *Mg.*	Kegonsa *Mg.*	Wingra *Mg.*
March 16	172	168	152	—	—
April 6–25	192	544	325	269	56
May 1–9	186	520	304	232	108
June 6–8	146	480	200	168	100
July 7–13	76	472	202	120	60
July 24–28	68	480	148	96	52
Aug. 7–12	72	256	96	104	60
Aug. 17–19	76	260	88	100	64
Sept. 8–17	80	310	89	95	70
Oct. 1	100	425	49	80	—
Oct. 3–5	150	435	60	95	62
Nov. 20–26	188	460	160	175	172
Dec. 5–10	205	485	180	195	192

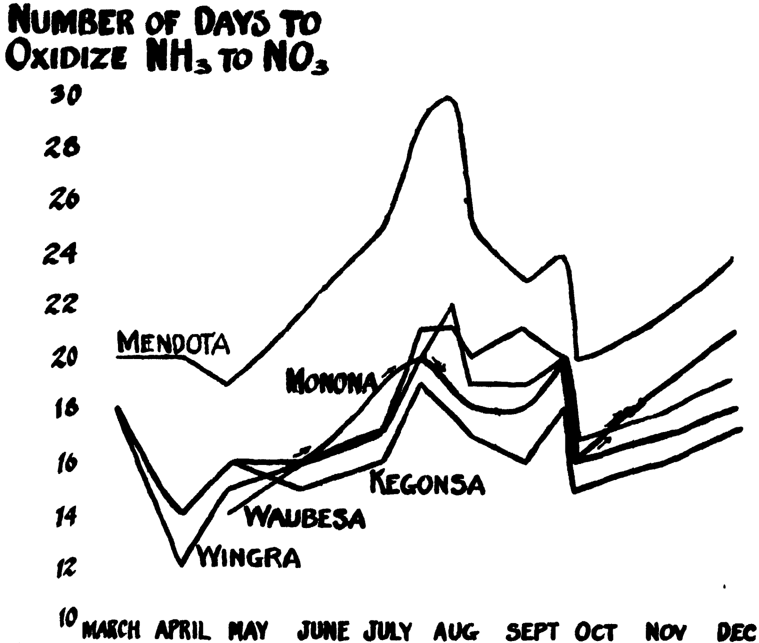
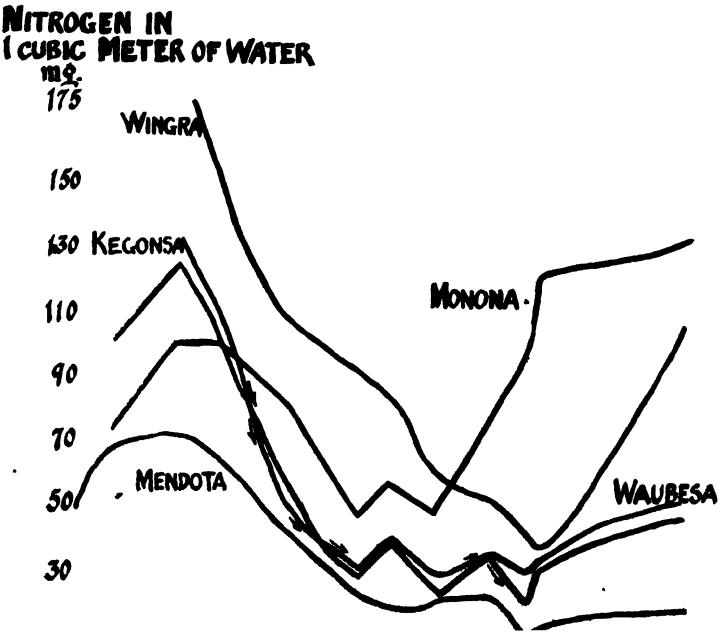


FIG. 4 - RATE OF NITRIFICATION IN LAKE WATERS



variations can be explained on the same basis as given for the organic nitrogen. The fluctuations in the ammonia content of Lake Monona need further explanation. The sources of ammonia are chiefly from the inflowing Mendota and Wingra waters, and the ammonia of the city sewage effluent which contains on an average about 12 p.p.m. of free ammonia (12,000 mgs. per cubic meter). About six million gallons (22,800 cubic meters) of this treated sewage effluent flow daily into the upper end of Lake Monona. During the early part of April, when the lake turnover had just taken place, the ammonia content of the surface water rose considerably due to the mixing of the high bottom ammonia with that of the surface. As the algae crop increased the ammonia dropped. Since Lake Monona was treated with copper sulfate in order to kill the algae as much as possible, the ammonia content in this lake did not show such a marked drop as was noticed in the other lakes. On one occasion, however, the ammonia in Monona did give a very sudden drop, together with a big growth of algae over the entire lake. This is a further proof of the feeding of these forms of life on ammonia. This incident occurred during the early part of August when the copper sulfate supply was exhausted. As soon as the copper treatments were begun again the ammonia content showed a decided gain. High ammonia necessary for nitrate production does not injure the nitrate bacteria by such a concentration and the process is similar to that occurring in soils.

TABLE 4.—*Rate of nitrification in the waters of the several lakes.*

50 cc. inoculum into 50 cc. of 0.1% $(NH_4)_2SO_4$ medium at 28°C.

	Time required for the oxidation of $(NH_4)_2SO_4$ to nitrates				
Date	Mendota	Monona	Waubesa	Kegonsa	Wingra
1925	*Days*	*Days*	*Days*	*Days*	*Days*
March 16	20	18	18		
April 6–25	20	14	12		
May 1–9	19	16	15	16	14
June 6–8	22	16	16	15	16
July 7–13	25	19	17	16	17
July 24–28	29	20	20	19	21
Aug. 7–12	30	19	22	18	21
Aug. 17–19	25	18	19	17	20
Sept. 8–17	23	18	19	16	21
Oct. 1	24	20	20	18	20
Oct. 3–5	20	16	17	15	17
Nov. 20–26	22	17	19	16	18
Dec. 5–10	24	18	21	17	21

RATE OF NITRIFICATION

The occurrence and the activity of nitrifying bacteria is shown in Table 4. All the lake waters show a slow rate of nitrification in midsummer and a more rapid rate in spring and fall. The lakes with a low ammonia and organic nitrogen content, as Mendota and Wingra, have a slower rate of nitrification than Waubesa and Kegonsa which have a higher ammonia and organic nitrogen content. Under normal conditions, one would expect Lake Monona to show the most rapid rate of nitrification due to its high ammonia content and the nitrifying bacteria coming from the sewage effluent. Yet due to the treatment of both the sewage effluent and of the lake water, the bacterial activity is checked to some extent. The rate seems to be related to a constant supply of nitrogen for the activity of the nitrifiers. With a constant supply of nitrogen an enrichment culture is built up in the lake.

TABLE 5.—*Nitrate nitrogen in 1 cubic meter of water of the several lakes.*

Date 1925	Mendota *Mg.*	Monona *Mg.*	Waubesa *Mg.*	Kegonsa *Mg.*	Wingra *Mg.*
March 4	47.0	——	——	——	——
March 16	67.0	73.5	101.6	——	——
April 6–25	72.0	100.0	125.5	131.5	175.0
May 1–9	64.0	99.0	100.0	110.0	150.0
June 6–8	42.0	80.0	56.0	50.0	106.0
July 7–13	23.0	48.0	28.0	30.0	93.0
July 24–28	20.0	56.0	37.0	39.0	85.0
Aug. 7–12	18.0	50.0	25.0	30.0	60.0
Aug. 17–19	20.0	48.0	22.0	28.0	55.0
Sept. 8–17	20.0	80.0	35.0	35.0	51.0
Oct. 1	10.0	105.0	30.0	21.0	——
Oct. 3–5	15.0	120.0	36.0	30.0	39.0
Nov. 20–26	17.0	128.0	48.0	42.0	80.0
Dec. 5–10	19.0	133.0	55.0	47.0	100.0

TABLE 6.—*Nitrate reduction in the waters of the several lakes.*

Date	Time required for the total destruction of nitrates[a]				
	Mendota	Monona	Waubesa	Kegonsa	Wingra
1925	*Days*	*Days*	*Days*	*Days*	*Days*
March 16	16	6	10	—	—
April 6–25	16	10	12	—	—
May 1–9	13	9	10	6	—
June 6–9	11	8	8	7	10
July 7–13	10	6	4	4	9
July 24–28	7	5	4	3	8
Aug. 7–12	6	7	6	3	9
Aug. 17–19	8	6	7	4	11
Sept. 8–17	10	8	9	5	12
Oct. 1	14	8	9	5	10
Oct. 3–5	12	7	5	3	8
Nov. 20–26	13	8	6	5	10
Dec. 5–10	14	10	8	7	12

[a] 1 cc. inoculum incubated at 28°C. Giltay's medium (0.01% KNO_3).

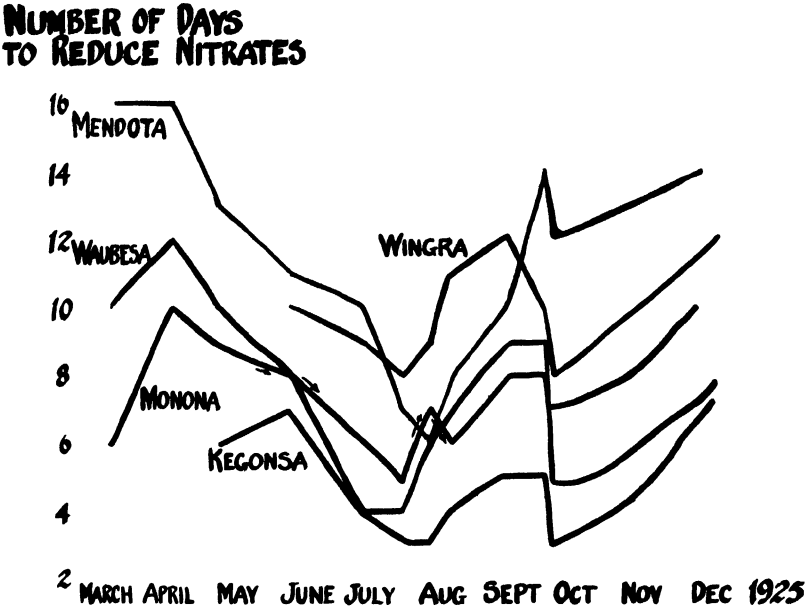


FIG. 6-RATE OF NITRATE REDUCTION IN LAKE WATER

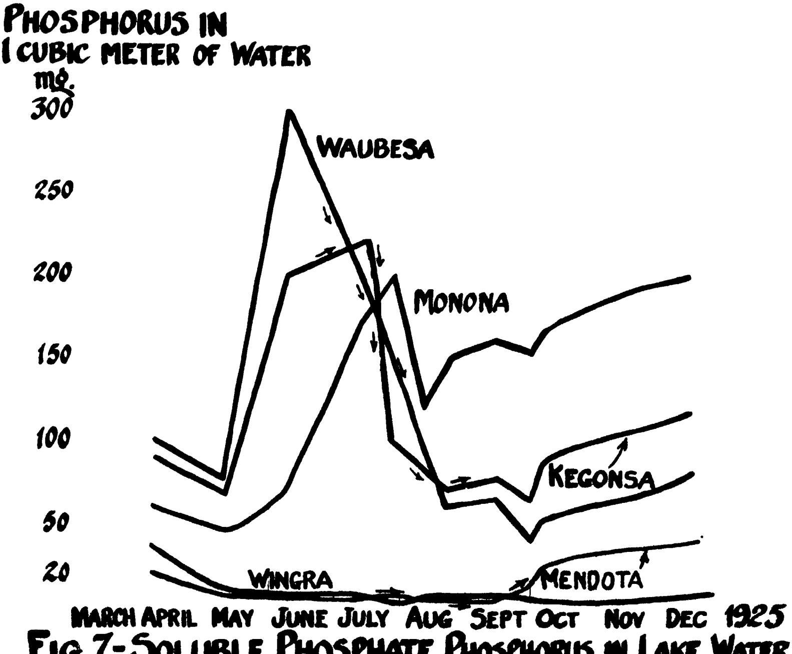


FIG. 7-SOLUBLE PHOSPHATE PHOSPHORUS IN LAKE WATER

NITRATE NITROGEN

In general the nitrate changes in the chain of lakes follow the same variations as the ammonia and the organic nitrogen. The nitrate content in each lake, as given in Table 5, shows a more marked decrease during the summer season than do the other forms of nitrogen. This is marked in the case of Lake Wingra which has a very high nitrate content in early spring due to the winter accumulation of the nitrates from the inflowing springs, and as soon as the heavy plankton crop begins to grow the nitrates drop rapidly.

RATE OF NITRATE REDUCTION

The bacterial nitrate reduction that occurs in the chain of lakes is given in Table 6. Nitrate reduction, just as nitrification, is taking place to some extent at all times of the year in the lake water. Yet during certain seasons the activity of one is much greater than the other. In the case of nitrate reduction the rate increased rapidly in the entire chain of lakes as the season advanced from spring to summer. In late summer when the lakes became depleted of their nitrate content the rate of reduction diminished, since the food supply for this process was practically gone. In October when the heavy rains caused a rise in the number of bacteria, and in the nitrogen and phosphorus content, the rate of reduction made a marked increase for a short time. A large source of energy for reduction is brought in along with a heavy inoculation. Although Lake Wingra has a larger amount of nitrate nitrogen present than the other lakes, yet the rate of reduction was found to be much slower. This is due in part to the lower number of bacteria in this lake and to the nature of the inflowing spring water.

TABLE 7.—*Soluble phosphate phosphorus in 1 cubic meter of water from the several lakes.*

Date 1925	Mendota *Mg.*	Monona *Mg.*	Waubesa *Mg.*	Kegonsa *Mg.*	Wingra *Mg.*
April 6–25	20.0	60.0	100.0	90.0	35.0
May 1–18	6.0	45.0	75.0	65.0	10.0
June 6–8	5.0	70.0	300.0	200.0	5.0
July 7–13	3.0	170.0	200.0	220.0	5.0
July 24–28	6.0	200.0	150.0	100.0	2.0
Aug. 7–12	3.0	120.0	90.0	80.0	3.0
Aug. 17–25	3.0	150.0	60.0	70.0	5.0
Sept. 8–17	1.0	160.0	65.0	75.0	7.0
Oct. 1	10.0	155.0	40.0	65.0	——
Oct. 3–5	20.0	165.0	50.0	85.0	3.0
Nov. 20–26	35.0	185.0	60.0	110.0	4.0
Dec. 5–10	39.0	200.0	73.0	125.0	5.0

SOLUBLE PHOSPHORUS

The soluble phosphorus content of these lakes as given in Table 7 shows the same variations as the different forms of nitrogen. As soon as the plankton increases the soluble phosphorus makes a sudden drop. The results from Lake Monona offer an exception to this rule. Apparently the destruction of algae by copper sulfate, and the inflowing sewage effluent brought about an increase in phosphates. In Lake Mendota and Lake Wingra the phosphorus content in the surface waters remained low all summer. This low content of phosphorus is probably due to the growth of the plankton. These forms of life use the soluble phosphorus as rapidly as it was formed or as it flowed into these lakes. The surface water of Lake Waubesa and Lake Kegonsa show a greater increase in phosphorus in May and June than the water of Lake Monona which is their chief source of supply. It seems probable that Lakes Waubesa and Kegonsa obtained the high phosphorus from the drainage waters of the surrounding farm lands.

II. THE EFFECT OF RAINFALL AND INFLOWING SPRING WATERS ON THE CHEMICAL AND BACTERIAL CONTENT OF LAKE WATERS

In order to study the influence of surface drainage upon the normal lake conditions, a number of water samples were collected in October before and after heavy rains. Throughout the summer until October the region surrounding these lakes had a very low rainfall. From October 3 to 6 heavy rains occurred and consequently much water flowed into these lakes. As given in Table 8, the inflowing waters as well as the lake waters showed a marked increase in total number of bacteria, in the activity of the bacteria, in organic matter, and in phosphorus, ammonia, and nitrates. In many cases following the rain the total number of bacteria almost doubled.

Fred, et al (9), in his study of the bacteria in Lake Mendota, also noticed the influence of drainage waters upon the number and kinds of bacteria. The soluble phosphorus and also the different forms of nitrogen show marked increases. The greatest gain was noted with ammonia nitrogen. After a rain the rate at which the nitrates are reduced was found to be doubled in some cases, whereas in others the rate of nitrification was increased more than the rate of reduction. Warner's spring water flowing into Lake Mendota showed very little change before and after the heavy rains. The data collected at the Black Hawk Ravine indicate that, in spite of the high number of bacteria and the different forms of nitrogen, the analysis of the water 150 feet away from where this water enters Lake Mendota shows a decided drop upon being diluted with the lake waters.

TABLE 8.—*Bacteriological and chemical content of Madison lakes as influenced by rain.*

Samples taken before and after rain, October 1–5, 1925		Number of bacteria per cc.[a]	Organic nitrogen	Soluble PO_4 phosphorus	Rate of denitrification[b]	NH_3 nitrogen	NO_3 nitrogen	Rate of nitrification[c]
			Mg. per cu. m.	*Mg. per cu. m.*	*Days*	*Mg. per cu. m.*	*Mg. per cu. m.*	*Days*
Lake Mendota	Before	1,250	855	10	14	100	10	24
	After	2,400	880	20	12	150	15	20
University Marsh	Before	3,010	755	30	8	95	755	20
	After	3,510	915	45	4	165	790	17
Black Hawk Ravine	After	16,050	1,030	25	2	555	155	9
150 feet from Black Hawk Ravine (into Lake Mendota)	Before	1,760	900	10	11	110	18	24
	After	8,870	955	13	9	205	50	15
Warner's Spring	Before	580	43	20	15	29	1,620	30
	After	810	50	25	15	32	1,640	28
Lake Monona	Before	1,975	895	155	8	425	105	20
	After	2,950	925	165	7	435	120	16
Drainage Canal into Monona	Before	4,370	905	21	6	100	251	21
	After	6,890	975	29	3	185	285	15
Lake Waubesa	Before	2,030	990	40	9	49	30	20
	After	3,170	1,010	50	5	60	36	17
Canal into Waubesa	After	7,650	1,255	55	2	195	184	16
Lake Kegonsa	Before	2,970	950	65	5	80	21	18
	After	4,150	970	80	3	95	30	15
Canal into Kegonsa	After	8,250	1,110	75	2	106	95	15

[a] Bacteria grown on nutrose agar at 28°C.

[b] Days to destroy nitrates completely; 1 cc. inoculum in 10 cc. of 0.01% KNO_3 medium.

[c] Days to change ammonia to nitrates; 50 cc. inoculum in 50 cc. of 0.1% $(NH_4)_2SO_4$ medium.

III. THE EFFECT OF INFLOWING SPRING WATERS ON THE NITRATE CONTENT OF LAKE WATERS

For this test two adjoining springs, Warner's and Merrill's, that flow into Lake Mendota were studied in order to notice at what rate their high nitrate content dilutes with the lake water. The combined flow of these two springs furnishes a large amount of high nitrate water to the lake. The results as shown in Table 9 indicate that the dilution is so great that about a mile away from where the springs enter the lake the water at Station IV is not influenced to a great extent.

TABLE 9.—*The extent to which inflowing waters affect the nitrate content of Lake Mendota.*

Feb. 4, 1924, Calculated for 1 cubic meter of water

	Nitrate nitrogen *Mg.*
Warner's Spring	2,858.0
Merrill's Spring	2,222.0
100 feet from Warner's Spring	981.0
200 feet from Warner's Spring	255.0
300 feet from Warner's Spring	146.3
450 feet from Warner's Spring	74.0
600 feet from Warner's Spring	36.9
Station IV (West Bay of Lake Mendota) surface	29.7
Station IV (West Bay of Lake Mendota) bottom	80.0

SUMMARY

The results show that variations in the different forms of nitrogen and soluble phosphorus in the water of these lakes are largely due to the biological activities. The algae, weeds, and nitrate-reducing bacteria are the essential factors that lower the nitrogen and phosphorus content of the lakes. The nitrifying bacteria aid in increasing the nitrate content.

Large amounts of spring waters and drainage waters after heavy rains influence the chemical and bacterial content of the lakes.

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LEGUME BACTERIA POPULATION OF THE SOIL[1]

J. K. WILSON[2]

Interest has been manifested from time to time in the number of legume bacteria that a soil will maintain. Such interest was probably stimulated by the practical problem of soil inoculation for legumes. Several attempts have been made to determine the number of such organisms in 1 gram of soil. These attempts have centered around the development of a specific medium that would permit the growth of the legume bacteria and exclude all others. This method of procedure has been disappointing because bacteria other than those of the leguminous type have also developed on the medium. If such a medium were used successfully in developing and determining only the colonies of the legume organism it would not tell whether the organisms belonged to the Medicago, Trifolium, or some other group. It is doubtful if such procedure will ever give the desired information for it is fairly well established that the reaction of the medium will have a dominating influence upon the group of legume bacteria that will develop.

Recently the writer[3] has presented data to show that soils may be deficient in legume bacteria, even though the soil had grown the host plant (*Vicia vellosa*) consecutively for nine years. Such data were obtained by counting the nodules on plant roots that had grown in the soil in comparison with those that had grown on roots in the same soil when the proper legume bacteria naturally present were supplemented with an artificial culture. Also in certain cases data were obtained which indicated that the bacteria for Trifolium and Medicago plants had nearly disappeared from the soil.

With these facts in mind, experiments were conducted to determine the approximate number of bacteria in soil for certain groups of plants, believing that such information would contribute something to the subject of soil inoculation for legumes.

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[1] Contribution from the Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication September 10, 1926.

[2] Professor of Soil Technology.

[3] This JOURNAL, 18:280–294. 1926.

METHODS OF WORK

In making dilutions of soil suspensions it is possible to arrive at a place where a definite part of a gram may no longer contain the sought for legume bacterium. Therefore, if a series of dilutions of a known soil are added to a sterile soil that is subsequently planted with sterile seed for the particular legume organism in question, a point should be reached where there is little chance that any nodules will appear on the host plant. This procedure has been adopted and the exact methods are outlined herewith.

SECURING AND HANDLING SAMPLES

Soil samples were collected from plats the history of which was known. They represented the soil below the first half inch and above the fifth inch.

To secure representative samples of each plat soil was collected from 20 places. This constituted a composite sample. The only exception to this was in case of samples taken from plat 3608. In this case soil was taken from five places and each treated as a composite. From the composite samples 100 grams were used for moisture determinations. The rest of each sample served as material from which dilutions were made. Enough of the sample was taken to secure either 100 or 500 grams of dry soil. This was triturated with water, made to definite volume, shaken 400 times, and dilutions made from the muddy suspension. All dilutions were made with sterilized water with the aid of sterile pipettes. Care was exercised throughout the work to avoid contamination with the legume organism. The final dilution, representing a definite amount of soil, was put either into the container where the host plant was to be grown or into the water that was used to bring the moisture of the soil to proper condition for growing the host plant.

Knowing that an acid soil is likely to be deficient in legume bacteria, it was difficult to estimate what quantity should be taken in order to establish a point where nodules would be produced and where they would not be produced. As a result various quantities of the soil suspension were used. The largest quantity was equivalent to 5 grams of soil and the smallest was equivalent to one five-millionth of a gram of soil. These portions were used in triplicate when tumblers were used as the culture container and either in duplicate or triplicate when the plants were grown in large test tubes.

SEED TREATMENT

As there is always the possibility of seed carrying the legume bacteria, it was thought best to treat the seed to remove any such organisms. All the seeds were treated, therefore, with a solution of calcium hypochlorite with the exception of Dalea seed which was placed in concentrated sulfuric acid for 30 minutes and subsequently thoroughly washed. After treatment the seed were carefully handled to prevent subsequent contamination.

NUMBER AND KINDS OF PLANTS

Several counts of the number of *Trifolium repens* plants in each culture showed 200 to 300; of *Vicia villosa*, 5 to 20: of Medicago or Meliotus, 100 to 200; of Soja, 3 to 10; and of Dalea 5 to 25

GROWING HOST PLANTS FOR NODULATION

Since the presence or absence of nodules on the host plant was to be the criterion of the presence or absence of the organism, a soil was selected as a medium which was known to be favorable for the growth of the legume organism and nodule production. This soil when used was air dry and was added in 360-gram portions either to large test tubes or to glass tumblers. The test tubes were plugged with cotton and each tumbler was covered with wrapping paper that was held in place by a rubber band. Both tubes and tumblers with soil were sterilized in live steam. Many tests made by growing plants in soil thus prepared showed that it contained no nodule bacteria and that the method was applicable to such a study.

After these containers were sterilized they received definite portions of the soil suspension to be studied. Certain portions may have only one or two legume bacteria in them. As nodule production is probably a chance contact between the host plant and the nodule bacteria, it may be that if the seed were sown immediately, nodule production would not occur. Consequently, the containers were allowed to stand for 10 to 14 days before planting. This incubation period should have permitted the establishment of a high legume bacteria content. After this period the desired host plant seed were inserted. When the legume bacteria representing two or more groups of host plants were to be determined in a composite sample from a field, it was possible to plant the seed of these various host plants together in the same containers. This reduced the number of containers necessary for the work and it is believed that this procedure in no way vitiated the results.

As soon as germination had occurred and the plantlets were in need of light, the containers were taken to the greenhouse and placed in running water so that a uniform temperature favorable for plant growth would be maintained. Water losses from each container were returned by adding distilled water.

Previous observations of nodule formation had revealed that 10 to 14 days was sufficient time for the development of macroscopic nodules on vetch, soybean, and red clover, while a longer period, about 21 days, is better for alfalfa. After this lapse of time the plants were carefully washed and placed in water under good illumination so that any nodules could be readily seen. Vetch was used as the host plant for the Pisum and Vicia group of bacteria, Medicago or Melilotus was used for the Medicago group, while *Trifolium pratense*, Soja, and Dalea were used for their respective groups of bacteria.

DETERMINING SOIL REACTION

The soil was extracted with two and one-half times its own weight of water and the extract filtered through washed filter paper. The pH values of the clear or opalescent solution thus obtained were determined colorimetrically.

RESULTS

The legume bacteria population of the soil, for convenience of inoculation purposes, has been divided by investigators into ten or more groups. Each group is more or less specific for certain plants. These various groups, if present in the same soil, exist in association. The more important ones from the standpoint of economic plants are Medicago and Melilotus, Pisum and Vicia, Soja, Trifolium, and Phoseolus. Other groups, such as Dalea and Lupinus, are of interest in some localities.

The number of legume bacteria of five groups have been determined in field soil and are reported in the present investigation.

BACTERIA OF THE PISUM GROUP

Samples of soil were collected from numerous plats and the number of bacteria capable of producing nodules on Vicia determined. The results of such determinations, together with other data, are given in Table 1.

The data show a wide difference in the number of legume bacteria in the soil which are capable of producing nodules on peas and vetch. It required about 1 gram of soil from plats 19, 36, and 37 to secure enough of these bacteria to produce nodules, while samples from plat 752 and range 5 carried the organism in 1/10,000 of a gram. It is also noticed that as a rule the greater the acidity of the soil the fewer the legume bacteria.

TABLE 1.—*Bacteria of the Pisum group.*

Plat No.	Years in vetch or peas	pH	Moisture in sample %	Part of gram used	
				Legume bacteria present in	Legume bacteria absent in
752	1917–1926	6.8	16.0	1/100,000	1/500,000
755	1917–1926	5.4	16.0	1/1,000	1/10,000
2114	Not since 1911	7.0	13.0	——[b]	2/5
2109	Not since 1911	6.8	13.0	——[b]	1/60,000
2008	Not since 1911	6.8	13.0	1/20,000	1/50,000
Range 5	1926	5.4	10.0	1/100,000	——[c]
3608	Not since 1922	6.2	18.0	1/1,000	1/10,000
	Not since 1922	6.4	18.0	1/1,000	1/10,000
	Not since 1922	6.6	18.0	1/1,000	1/10,000
	Not since 1922	6.8	18.0	1/10,000	1/100,000
	Not since 1922	7.0	18.0	1/10,000	1/100,000
19	Unknown[a]	5.6	3.9	——[b]	1
36	Unknown[a]	5.8	4.7	——[b]	1
37	Unknown[a]	6.0	3.7	——[b]	1
54	Unknown[a]	6.0	3.5	1/2	1/10
68	Unknown[a]	6.4	4.6	1/10	1/50
Dalea (limed)		6.2	4.4	1/10	1/50
Dalea (unlimed)		5.4	3.3	1/10	1/50

[a] In pasture previous to 1925.

[b] Not large enough quantity used.

[c] No part smaller than 1/100,000 used.

TABLE 2.—*Bacteria of the Trifolium group.*

Plat No.	Years in Trifolium	pH	Moisture in soil %	Part of gram used	
				Legume bacteria present in	Legume bacteria absent in
2109	1926	6.8	13	1/1,000,000	1/5,000,000
2114	1926	7.0	13	1/1,000,000	1/2,000,000
3608	Not since 1922	6.2	18	1/100,000	1/1,000,000
	Not since 1922	6.4	18	1/100,000	1/1,000,000
	Not since 1922	6.6	18	1/100,000	1/1,000,000
	Not since 1922	6.8	18	1/100,000	1/1,000,000
	Not since 1922	7.0	18	1/1,000,000	——[b]
752	Not since 1910	6.8	16	1/1,000	1/10,000
755	Not since 1910	5.4	16	1/50	1/500
Dalea[a]	Wild vegetation	5.4	3.3	1/1,000	1/5,000
	for years	6.2	4.4	1/10,000	1/50,000

[a] Planted to Dalea in 1925.

[b] No part smaller than 1/1,000,000 used.

BACTERIA OF THE TRIFOLIUM GROUP

In Table 2 are presented data concerning the number of legume bacteria per gram of soil that are capable of producing nodules on *Trifolium repens*.

These data indicate that soils may have as few as 50 or more than a million legume organisms per gram of soil which are capable of producing nodules on *Trifolium repens*. This wide variation seems to be more closely associated with the reaction of the soil than with the frequency of the host plant on the soil. Plat 755 with a reaction pH 5.4 did not have the organisms in 1/500 of a gram, while the adjoining plat 752 with a pH 6.8 contained between 1,000 and 10,000 in the same quantity of soil. Neither of these plats had grown the host plant since 1910. Again, the Dalea plat soil that had a pH 5.4 contained between 1,000 and 5,000 per gram of soil, while the same soil that had received calcium carbonate one year previously with a pH 6.2 contained between 10,000 and 50,000 per gram.

BACTERIA OF THE MEDICAGO GROUP

The results secured in a study of the number of bacteria in the soil capable of producing nodules on alfalfa (Medicago) or sweet clover (Melilotus), together with other data, are presented in Table 3.

TABLE 3.—*Bacteria of the Medicago group.*

Plat No.	Years in alfalfa	pH	Moisture in sample	Part of gram used	
			%	Legume bacteria present in	Legume bacteria absent in
752	1905 to 1911	6.8	16.0	1/50	1/500
755	1905 to 1911	5.4	16.0	———[b]	3
2008	1926	6.8	13.0	1/100,000	———[d]
19	On sweet clover 1925 and 1926	5.6	3.9	1/50	1/100
36	1925 and 1926	5.8	4.7	1/10	1/50
37	1295 and 1926	6.0	3.7	1/10,000	1/50,000
54	1925 and 1926	6.0	3.5	1/10,000	1/50,000
68	1925 and 1926	6.4	4.6	1/10,000	1/50,000
3608	In alfalfa 1922[a]	6.2	18.0	———[c]	5
	In alfalfa 1922[a]	6.4	18.0	———[c]	5
	In alfalfa 1922[a]	6.6	18.0	1/10	1/100
	In alfalfa 1922[a]	6.8	18.0	1/1,000	1/10,000
	In alfalfa 1922[a]	7.0	18.0	1/1,000	1/10,000

[a] Sown to alfalfa in 1922. At pH 6.6 to 7.0, alfalfa was good. On soil pH 6.4 to 6.2 only now and then a few alfalfa plants. Samples collected July 20, 1926.

[b] No quantity larger than 3 grams used.

[c] No quantity larger than 5 grams used.

[d] No quantity smaller than 1/100,000 of a gram used.

From these figures it is evident that there is a great variation in the number of organisms of this group per gram of soil which are capable of producing nodules on Medicago or Melilotus. In two cases as much as 5 grams failed to carry the organism, while in others it was present in 1/100,000 of a gram. In one case, where the reaction was pH 6.8, the number was greater than 100,000 per gram.

Plat 3608 was seeded to alfalfa in 1922. By 1926 the alfalfa had very largely disappeared from one end of the plat, leaving a rather sharp line where alfalfa would grow and where it would not grow. On this line the soil was pH 6.6. Three feet away from this line on the side where alfalfa had failed it was pH 6.4 and 6 feet away it was pH 6.2. Three feet into the alfalfa it was pH 6.8 and 6 feet into the alfalfa it was pH 7.0. This is a perfect correlation of pH and the growth of the host plant and the bacteria. Six feet from the line of alfalfa growth, where the hydrogen-ion concentration was pH 6.2, 5 grams of soil failed to carry the organism. On the line of growth of alfalfa the pH was 6.6 and about 0.1 gram of soil was used before the organism was found. Six feet into the alfalfa, where the soil reaction was pH 7.0, the number of organisms was somewhere between 1,000 and 10,000 per gram. The moisture content of these five samples was the same.

Plat 2008 which was growing alfalfa when the sample was collected had more than 100,000 organisms per gram of soil which were able to produce nodules on alfalfa seedlings.

The effect of the reaction of the soil on the number of legume organisms is also brought out when the results of plats 19 and 36 are compared with those of 54 and 68. The former two have a pH 5.6 and 5.8 with a legume bacteria content of about 50 per gram of soil, while the latter two with pH 6.0 and 6.4 have more than 10,000 per gram. The moisture content of the soil from these plats was about equal.

Plats 752 and 755 grew alfalfa several years previous to 1911. Plat 752 has received a total of 4,000 pounds of limestone per acre since 1910, while plat 755 has received none. The soil of both plats seems to be low in legume bacteria for alfalfa when compared with the number in soil from plat 2008. This might suggest that some other factor than the reaction of the soil may cause the legume organism to disappear.

BACTERIA OF DALEA GROUP AND OF SOJA GROUP

The bacteria for the Dalea group of plants were determined in a soil that had not received lime and in one that had received about 4,000 pounds per acre in 1925. Those for the soybean group were determined in one soil only. The necessary data are presented in Table 4.

The data show that for Dalea seeded and inoculated in 1925 a difference in reaction of the soil resulted in a difference in the number of legume bacteria. The sample with pH 5.2 had between 10,000

TABLE 4.—*Bacteria of Dalea group and of Soja group.*

Plat	Years in crop	pH	Moisture in sample %	Part of gram used: Legume bacteria present in	Part of gram used: Legume bacteria absent in
Bald Hill	In Dalea 1925–26	5.4	3.3	1/10,000	1/50,000
Bald Hill	In Dalea 1925–26	6.2	4.4	1/50,000	Not determined
Range 5	In soybean 1924–25	5.4	10	1/100,000	Not determined

and 50,000 per gram of soil, while the same soil with a pH 6.2 had over 50,000 per gram of soil. Apparently a soil with a reaction pH 5.4 is too acid for the best growth of this group of bacteria.

Only one determination was made of the number of organisms of the Soybean group in soil. This soil grew soybeans in 1924 and 1925. The sample of soil for determining the presence of the legume bacteria was collected July 20, 1926. It was growing field peas when the sample was taken. It had a reaction pH 5.4 and contained at least 100,000 soybean bacteria per gram of soil.

DISCUSSION

The results of this study of the number of legume bacteria in field soils leads to the conclusion that there is a wide variation in the number of such bacteria per gram of soil, and that certain groups of these bacteria are more sensitive to soil reaction than are others. As much as 5 grams of soil, the reaction of which was pH 5.4, did not contain the bacteria capable of producing nodules on alfalfa (Medicago), while another soil with a reaction pH 6.8 contained enough bacteria to produce nodules when 1/100,000 of a gram was used. This was somewhat the case with other groups of bacteria studied.

If the number of bacteria of the Medicago group found in a soil with a pH 6.8 and which was growing alfalfa when sampled is taken as a normal number, then a soil with reaction pH 6.2 to 6.0 seems to reduce materially the number of legume organisms for Medicago; while one with pH 6.0 to 5.4 is quite fatal to their continued presence. A soil reaction pH 5.4 seems also very unfavorable for Vicia and Trifolium groups of the bacteria, while a reaction nearer neutrality than pH 6.0 to 6.2 appears more favorable for their presence.

These results confirm the findings of the author on a study of nodulation and artificial cultures for legumes in which it was reported that the number of nodules on Medicago, Vicia, Trifolium, and Soja may be increased if the number of legume bacteria in the soil for the specific host plant was increased by means of an artificial culture, especially so if the acid reaction of the soil was farther from neutrality than pH 6.0.

CONCLUSIONS

Soil samples were collected from fields whose crop history for a number of years was known. These samples were examined for legume bacteria of different groups of host plants. Definite portions of the soil were used as inoculation material for sterilized soil that was prepared either in large test tubes or in glass tumblers. Seeds of the desired host plant, after proper treatment to remove any adhering legume bacteria, were planted in these soils.

The containers holding these planted soils were placed in running water so that favorable conditions for nodulation would be maintained. After proper intervals of growth the plant roots were examined for nodules. The presence or absence of nodules on the roots was the criterion of the number of legume bacteria in the soil.

Soils thus handled showed a wide variation in the number of legume bacteria. For alfalfa the number ranged from none in 5 grams to 100,000 per gram.

A soil with a reaction further from neutrality than pH 6.4 does not support as large a number of legume organisms capable of producing nodules on alfalfa as one the reaction of which is nearer neutrality than this figure indicates.

The growth of the legume organism for *Trifolium repens* seemed to be reduced in soil when the reaction was about pH 6.0. In a soil that had a reaction pH 5.4 there were only about 50 organisms per gram, while one with a reaction pH 6.8 had more than a million per gram. The moisture content of these two soils was not the same and this may account for some of the difference.

Soil with a reaction pH 6.2 contained a larger number of organisms capable of producing nodules on Dalea than one with a reaction pH 5.4.

One soil with pH 5.4 contained more than 100,000 bacteria per gram for each of two plant groups. These were soybean and vetch.

REGISTRATION OF STANDARD WHEAT VARIETIES[1]

J. Allen Clark, H. H. Love and E. F. Gaines[2]

At the sixteenth annual meeting of the American Society of Agronomy, held at Chicago, Ill., in November, 1923, the "Committee on Methods of Registration" presented a detailed plan for the registration of wheat, oat and barley varieties. The plan, entailing cooperation between the American Society of Agronomy and the Bureau of Plant Industry of the United States Department of Agriculture, was approved and published (Jour. Am. Soc. Agron. 15: 527–529, 1923) by the Society. Subcommittees for each of the three crops, wheat, oats and barley, were appointed by the Society. M. A. McCall, representing the United States Department of Agriculture, was appointed to have charge of the register under the cooperative agreement with the Bureau of Plant Industry.

The writers of this report were the 1924 subcommittee of the American Society of Agronomy for the registration of wheat varieties. Acting on the suggestion of the "Committee on Varietal Standardization," this subcommittee approved for registration all of the varieties described in the Classification of American Wheat Varieties, U. S. Department of Agriculture Bulletin No. 1074, this classification having been approved by the American Society of Agronomy. There were 229 varieties keyed and described as distinct varieties, although they were known by more than 800 names. The official name and registration number of these 229 varieties are given below.

Varietal name	Registration No.	Varietal name	Registration No.	Varietal name	Registration No.
Winter Bluestem	1	Dart	18	Buffum No. 17	34
Martin	2	Gypsum	19	Leap	35
Prohibition	3	Surprise	20	Ontario Wonder	36
Greeson	4	Dicklow	21	Zimmerman	37
White Winter	5	Bobs	22	Walker	38
Challenge	6	Quality	23	Harvest Queen	39
Eaton	7	White Fife	24	Prosperity	40
White Wonder	8	White Federation	25	Forward	41
Satisfaction	9	Lynn	26	Squarehead	42
Early Defiance	10	Regenerated Defiance	27	Red Russian	43
Colorado No. 50	11	New Zealand	28	Sol	44
Touse	12	Pilcraw	29	Oakley	45
Defiance	13	Rice	30	Wyandotte	46
Rink	14	Minhardi	31	Flint	47
Bunyip	15	Lofthouse	32	Fultz	48
Pacific Bluestem	16	Big Frame	33	Ashland	49
Mexican Bluestem	17			Trumbull	50

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[1] Received for publication, September 15, 1926.

[2] Members of the 1924 Subcommittee for the Registration of Wheat Varieties.

Varietal name	Registration No.
Fultzo-Mediterranean	51
Kinney	52
Purplestraw	53
Huston	54
Alton	55
Red Bobs	56
Marquis	57
Red Fife	58
Power	59
Glyndon	60
Rysting	61
Wellman	62
Early Red Fife	63
Ghirka	64
Ruby	65
Kitchener	66
Climax	67
Kofod	68
Dawson	69
Honor	70
Schonacher	71
Arcadian	72
Windsor	73
Goldcoin	74
John Brown	75
Allen	76
Federation	77
Foisy	78
Hard Federation	79
Gold Drop	80
Homer	81
Red Wave	82
Fleming	83
Peterson	84
Odessa	85
Ruddy	86
Rupert	87
Rural New Yorker No. 6	88
Squareheads Master	89
Currell	90
Winter Chief	91
Poole	92
Portage	93
Russian Red	94
China	95
Wheedling	96
Red May	97
Illini Chief	98
Red Clawson	99
Rochester	100
Red Chief	101
Schlanstedt	102
Resaca	103
Stanley	104
Silvercoin	105
Jumbuck	106
Indian	107
Triplet	108
Mealy	109
Jones Fife	110
Haynes Bluestem	111
Dakota	112
Galgalos	113
Sonora	114
Grandprize	115
Democrat	116
Seneca Chief	117
Oatka Chief	118
Mammoth Amber	119
Palisade	120
Propo	121
Treadwell	122
Baart	123
Talimka	124
Nebraska No. 28	125
Gladden	126
Gipsy	127
Valley	128
Wisconsin Pedigree No. 40	129
Sibley	130
Fulcaster	131
Mammoth Red	132
Diamond Grit	133
Golden Cross	134
Champlain	135
Java	136
Erivan	137
Converse	138
Minturki	139
Hussar	140
Pesterboden	141
Blackhull	142
Turkey	143
Iowa No. 404	144
Iowa No. 1946	145
Montana No. 36	146
Nebraska No. 60	147
Wisconsin Pedigree No. 2	144
Kanred	148
Beloglina	159
Bacska	150
Preston	151
Kota	152
Pioneer	153
Rudy	155
Gluten	156
Nigger	157
Silversheaf	158
Fretes	159
Dixon	160
Chul	161
Link	162
Emerald	163
Genesee Giant	164
Canadian Red	165
Longberry No. 1	166
New Amber Longberry	167
Sevier	168
Diehl-Mediterranean	169
Russian	170
Imperial Amber	171
Goens	721
Cox	173
Yaroslav	174
Huron	175
Norka	176
Ladoga	177
Laramie	178
Ariette	179
Mediterranean	180
Red Rock	181
Bearded Winter Fife	182
Read	183
Rural New Yorker No. 57	184
Pride of Genesee	185
Virginia	186
Prelude	187

Varietal name	Registration No.	Varietal name	Registration No.	Varietal name	Registration No.
Humpback	188	Mayview	204	Marouani	218
Penquite	189	*(Poulard)*		Velvet Don	219
Hybrid 128	190	Clackamas	205	Golden Ball	220
Little Club	191	Alaska	206	Kahla	221
Big Club	192	Titanic	207	*(Emmer)*	
Hybrid 143	193	Winter Alaska	208	Khapli	222
Hybrid 60	194	*(Durum)*		Vernal	223
Hybrid 63	195	Pentad	209	Black Winter	224
Hybrid 108	196	Peliss	210	*(Spelt)*	
Hybrid 123	197	Acme	211	White Spring	225
Jenkin	198	Monad	212	Alstroum	226
Redchaff	199	Arnautka	213	Red Winter	227
Bluechaff	200	Mindum	214	Bearded Spelt	228
Dale	201	Kubanka	215	*(Polish)*	
Coppei	202	Kubanka No. 8	216	White Polish	229
Wilbur	203	Buford	217		

The above wheats are here registered as standard varieties. Certificates of registration will not be issued for these, but will be issued for improved varieties registered on the basis of performance in comparison with these standard varieties.

REGISTRATION OF IMPROVED WHEAT VARIETIES[1]

J. Allen Clark, H. H Love and J. H. Parker[2]

The registration plan of the American Society of Agronomy provides for registration of new varieties on the basis of performance, preferably at state or federal experiment stations. In order to be approved for registration a new variety also must be grown commercially or be of value and used in wheat breeding. Since the publication of the "Classification of American Wheat Varieties" by Clark, Martin and Ball (2),[3] numerous new varieties have been developed and grown. Applications for the registration of most of these have been received by the committee. For those which have been approved, registration numbers have been assigned and certificates of registration have been issued to the applicant. The varieties approved, together with their registration numbers, are as follows:

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[1] Received for publication September 15, 1926.

[2] Members of the 1925–1926 Subcommittee for the Registration of Wheat Varities.

[3] Reference by number is to "Literature Cited," p. 934.

Varietal name	Registration No.	Varietal name	Registration No.	Varietal name	Registration No.
Fulhio	231	Webster	239	Mosida	247
Ilred	232	Hope	240	Ridit	248
Michikof	233	Ceres	241	Sherman	249
Progress	234	Nodak	242	Regal	250
Ashkof	235	Reliance	243	White Odessa	251
Iobred	236	Karmont	244	Onas	252
Marquillo	237	Newturk	245	Shepherd	253
Minard	238	Akrona	246		

The information which is the basis for registering these varieties is given below.

FULHIO—Reg. No. 231

Fulhio (Ohio No. 127, C. I. No. 6999) was developed at the Ohio Agricultural Experiment Station, as a pure-line selection from Fultz. The selection was made at Wooster, Ohio, in 1912, by C. G. Williams, of the Department of Agronomy. Robt. M. Salter applied for its registration. The variety has been commercially grown in Ohio for several years. It is similar to Fultz except that the spikes are more erect. The suggested place in the present classification is between Flint (Reg. No. 47) and Fultz (Reg. No. 48). The superior characters of Fulhio are high yield, good tillering capacity, winter hardiness, fairly stiff straw, and somewhat greater resistance to loose smut than that of Fultz. It has been grown experimentally for 13 years at Wooster, Ohio, and at 13 other points in Ohio, beginning with nursery rows and later in 1/10th acre plats. The plat yields at Wooster for the five years, 1920 to 1924, inclusive, in comparison with Fultz, are as follows:

Varieties	1920	1921	1922	1923	1924	Average
Fulhio (new)	19.1	31.9	31.0	46.0	37.3	33.1
Fultz (standard)	16.6	27.7	26.8	45.9	30.7	29.5

For further information see bulletin by Thatcher (15).

ILRED—Reg. No. 232

Ilred (Ill. Turkey 10–110; C. I. No. 8219) was developed at the Illinois Agricultural Experiment Station by L. H. Smith, as a pure-line selection from Turkey. The selection was made at Urbana, Ill., in 1910. The variety has been grown commercially in Illinois since 1923. It is similar in appearance to Turkey, the suggested place in the classification being between Turkey (Reg. No. 143) and Iowa No. 404 (Reg. No. 144). The superior character of Ilred is that it is a high-yielding pure strain of Turkey. It has been tested 8 years at Urbana, Ill. The comparative data of Ilred and Turkey grown in plats replicated four times during the five years, 1920 to 1924, inclusive, are as follows:

Varieties	1920	1921	1922	1923	1924	Average
Ilred (new)	45.8	30.9	35.7	40.6	43.8	39.4
Turkey (standard)	44.2	32.2	35.6	35.7	40.3	37.6

For further information see bulletin by Stark (13).

MICHIKOF—Reg. No. 233

Michikof (Purdue No. 14C–5–3–5; C. I. No. 6990) was developed by the Indiana Agricultural Experiment Station in the Department of Soils and Crops of Purdue University. It was developed from a cross made in 1912 between

Michigan Amber (female) and Malakof (male). The selection from which the variety resulted was made in 1915. It is a tip-awned or awnletted variety of hard red winter wheat. Its suggested place in the present classification is after Alton (Registration No. 55). The superior characters of the Michikof variety are winter hardiness and a hard, glutinous kernel of high test weight, producing flour of superior quality for bread-making purposes. It has been grown commercially in Indiana for several years and has been tested for a ten-year period on the Soils and Crops farm and at outlying experiment stations in Indiana. The following are average yields secured in experiments at Huntington, Lafayette and Wanatah, during the four-year period from 1922 to 1925, inclusive.

Varieties	1922[a]	1923	1924	1925	Average
Yield					
Michikof (new)	19.8	29.0	20.0	15.3	21.0
Rudy (standard)	22.6	25.4	16.5	14.4	19.7
Test weight					
Michikof (new)	61.5	59.0	60.5	61.0	60.5
Rudy (standard)	59.3	56.0	58.5	60.0	58.5

[a] Michikof sown at 5 pecks in 1922, in all other instances sown at 6 pecks. Rudy sown at 7 pecks.

For further information see circular by Wiancko (18).

PROGRESS—Reg. No. 234

Progress (Wisc. Ped. M–16–11; C. I. 6902) was developed at the Marshfield Branch Station operated by the Department of Agronomy of the University of Wisconsin. It is the result of a selection made from a field of the Java variety made in 1916 by E. J. Delwiche. The Progress variety is similar to Java, but is much more resistant to stem rust and is a better yielder. The suggested place for Progress in the present scheme of classification is after Java (Reg. No. 136). Under Wisconsin conditions it is much earlier than Marquis. The variety has been grown at the Ashland, Madison, Marshfield and Sturgeon Bay stations and in cooperative tests with farmers in Wisconsin and at experiment stations in neighboring states, since 1916. The annual and average yields of Progress and Marquis at the Ashland and Marshfield stations from 1920 to 1925, inclusive, are as follows:

Varieties and Station	1920	1921	1922	1923	1924	1925	Average
Ashland							
Progress (new)	18.3	11.4	15.5	21.9	28.5	20.0	19.3
Marquis (standard)	13.1	6.1	11.8	5.2	21.0	19.1	12.7
Marshfield							
Progress (new)	6.9	16.4	12.8	23.7	12.7	21.5	15.7
Marquis (standard)	3.1	6.7	10.8	12.5	7.3	12.2	8.8

ASHKOF—Reg. No. 235

Ashkof (Wisc. 11–825; C. I. No. 6680) was developed at the Ashland Branch Station of the Department of Agronomy, University of Wisconsin. It is a pure-line selection from the Malakof variety made by E. J. Delwiche in 1911. The Ashkof variety is similar to the Hungarian type of hard red winter wheats, except that the glumes are brown. It more closely resembles the Pesterboden variety than Turkey. The suggested place in the present classification is after Yaroslav (Reg. No. 174). The superior characters of Ashkof wheat are winter hardiness and high yield. It has been grown for 14 years at the Ashland Branch Station and other stations in Wisconsin, and has been included in the uniform winterhardiness nurseries at numerous experiment stations in the United States and Canada since 1922. The annual and average yields of Ashkof in comparison with Wisconsin Pedigree No. 2 at the Ashland station for the five-year period 1920 to 1924, inclusive, are as follows:

Varieties	1920	1921	1922	1923	1924	Average
Ashkof (new)	40.1	31.5	40.0	24.9	40.1	35.3
Wisconsin Pedigree No. 2 (standard)	35.9	22.6	40.0	16.2	31.0	29.1

The new variety also has been high-yielding at the Madison and Marshfield stations. It has been grown commercially in Wisconsin for the past three years.

IOBRED—Reg. No. 236

Iobred (Iowa 1949; C. I. No. 6934) was developed at the Iowa Agricultural Experiment Station in cooperative experiments with the Office of Cereal Crops and Diseases Bureau of Plant Industry, U. S. Department of Agriculture. It was developed from a selection of the Banat variety (Iowa No. 1661) made in 1915 by L. C. Burnett. It is a bearded, brown-glumed variety of hard red winter wheat, the kernels of which are much shorter and broader than most of the wheats of that class. The suggested place in the scheme of classification is before the Yaroslav variety (Reg. No. 174). The superior characters of the Iobred variety for Iowa conditions are winter hardiness, strong straw, and good yields. The glume color and kernel shape of this variety facilitate identification and make it easy to keep the variety pure and to certify seed. The annual and average plat yields at Ames during the six years, 1920 to 1925, inclusive, in comparison with the parent Banat and the standard Turkey and Kanred varieties, are as follows:

Varieties	1920	1921	1922	1923	1924	1925	Average
Iobred (new)	40.0	19.3	47.3	36.0	50.0	30.3	37.2
Banat (parent)	27.5	15.7	43.5	37.6	51.4	32.2	34.7
Turkey (standard)	38.2	19.3	42.3	43.4	58.3	34.5	39.3
Kanred (standard)	38.0	21.6	50.8	41.7	47.8	31.3	38.5

Iobred has been grown commercially in Iowa since 1923.

MARQUILLO—Reg. No. 237

Marquillo (Minn. No. 2202; C. I. No. 6887) was developed at the Minnesota Agricultural Experiment Station in cooperative experiments with the Office of Cereal Crops and Diseases Bureau of Plant Industry, U. S. Department of Agriculture. It is the result of a cross made in 1914 between Marquis (female) and Iumillo durum (male). The selection II–15–44 was made in 1918. Application for registration was made from the plant breeding section of the Minnesota station. Marquillo is very similar to Marquis, although it is somewhat earlier in maturity and is more resistant to attacks of black stem rust (*Puccinia graminis tritici*). It has good strong straw and under Minnesota conditions has been a slightly better yielder than Marquis. The suggested place in the present classification is after Marquis (Reg. No. 57). Marquillo has been grown experimentally at University Farm, St. Paul, at the substations in Minnesota, and at stations in North Dakota, Montana and Canada. The nursery experiments have been conducted in rod rows, 3 rows per plat, systematically distributed three or four times, the center row used being to determine yield. The plat experiments in Minnesota were grown on 1/40th acre plats, systematically replicated three or four times with the outer two drill rows removed. The annual average yields and the percentages of stem rust infection for Marquillo and Marquis at the different stations are as follows:

Comparative Yielding Ability and Percentage of Rust Infection of Marquis and Marquillo.[a]

Type of experiment	Locality	Year of test	Yield in bushels per acre Marquis	Yield in bushels per acre Marquillo	Percentage rust infection Marquis	Percentage rust infection Marquillo
Nursery rows	Univ. Farm, St. Paul	1921	18.4	16.1	0	0
		1922	36.0	40.0	41	T
		1923	31.0	32.4	22	T
		1924	26.9	22.7	0	0
		1925	35.4	35.6	34	5
		Aver.	29.5	29.4		
	Waseca, Minn.	1922	19.7	29.1	35	3
		1923	22.2	22.6	23	4
		1925	19.1	16.1	27	2
		Aver.	20.3	22.6		
	Crookston, Minn.	1922	28.1	26.8	20	2
		1923	15.8	21.8	58	T
		1925	26.1	32.6	82	13
		Aver.	23.3	27.0		
	Morris, Minn.	1922	24.8	27.2	24	0
		1923	16.4	21.8	88	15
		1925	17.8	23.7	65	3
		Aver.	19.7	24.2		
	Average of six localities in Canada	1923	28.2	37.4	30–75	5–15
		1924	28.8	26.2	0–45	0–3
		Aver.	28.5	31.8		
	Mandan, N. Dak.	1924	21.8	22.6	24	3
	Dickinson, N. Dak.	1923	11.2	15.7	50	20
		1924	20.9	11.8[b]	25	5
		Aver.	16.1	13.8		
	Moccasin, Mont.	1923	36.6	37.7	0	0
		1924	36.9	32.4	0	0
		Aver.	36.8	35.1		
	Fargo, N. Dak.	1924	38.4	37.0	64	2
	North Platte, Nebr.	1924	31.4	25.1	0	0
Plats	Crookston, Minn.	1924	20.5	30.0	95	50
		1925	27.9	37.7	68	10
		Aver.	24.2	33.9		
	Morris, Minn.	1924	28.9	27.9	42	1
		1925	17.6	20.6	100	15
		Aver.	23.3	24.3		
	Waseca, Minn.	1924	37.2	42.1	80	1
		1925	24.6	23.3	83	T
		Aver.	30.9	32.7		
	Grand Rapids, Minn.	1924	15.0	15.4	87	42
		1925	19.2	21.3	10	10
		Aver.	17.1	18.4		
	Univ. Farm, St. Paul	1924	33.3	32.0	0	0
		1925	29.2	31.4		
		Aver.	31.3	31.7		
	Moccasin, Mont.	1924	32.0	31.5	0	0
	Brandon, Man.	1924	44.0	55.3	70	20

[a] Acknowledgment is made to various investigators who have kindly furnished comparative data which they have taken. Through such cooperation a comparison under many different conditions has been made possible. The data obtained from 6 places in Canada were furnished by Prof. W. P. Fraser; Mr. J. A. Clark, of the U. S. Department of Agriculture, furnished data from Mandan and Dickinson,

N. Dak., and Moccasin, Mont.; Prof. L. R. Waldron furnished the data from Fargo; Mr. S. J. Sigfusson furnished the report from Brandon, Manitoba, Canada. The data collected at the branch stations in Minnesota were obtained from Prof. A. C. Arny for the 40th-acre plat tests. The various branch station agronomists, R. E. Hodgson, Waseca; R. O. Bridgford, Morris; R. S. Dunham, Crookston; O. I. Bergh, Grand Rapids; and M. J. Thompson, Duluth, assisted in the collecting of data obtained from the branch stations.

[b] Probably the result of root rot.

For further information see Hayes, Stakman and Aamodt (9).

MINARD—Reg. No. 238

Minard (Minn. No. 2199; C. I. No. 6690) was developed by the Minnesota Agricultural Experiment Station at University Farm, St. Paul, Minn. It is the result of a cross made in 1902 between Turkey and an unknown variety, the selection from which the variety was developed being made in 1915. Minard is similar to Turkey, except that it produces exceptionally hard and corneous kernels under Minnesota conditions. The suggested place in the present classification is after Iowa No. 1946 (Reg. No. 145). Because of its good kernel characters and yielding ability, Minard is being used at University Farm, St. Paul, Minn., in breeding winter-hardy wheats of better quality. Minard has been grown at University Farm and at the substations in Minnesota since 1915. The yields obtained in comparison with those of Minturki, the best winter variety for Minnesota, are as follows:

Minard and Minturki Winter Wheats.

Type of plat	Locality	Year of test	Yield in bushels per acre Minard		Yield in bushels per acre Minturki	
Nursery	Univ. Farm, St. Paul	1916	33.2		38.7	
		1917	44.2		47.5	
		1918	20.8		20.9	
		1919	29.3		38.5	
		1920	34.1		38.4	
		1921	19.1		24.1	
		1922	25.9		26.7	
		Aver.		29.5		33.5
Plats	Univ. Farm, St. Paul	1918	28.7		28.7	
		1919	26.9		27.2	
		1920	30.1		32.7	
		1921	13.8		14.0	
		1922	10.2		13.3	
		1923	25.7		28.7	
		1924	48.6		41.5	
		Aver.		26.3		26.6
	Morris, Minn.	1922	27.3		28.0	
		1923	14.8		17.2	
		1924	45.0		45.7	
		Aver.		25.7		30.3
	Waseca, Minn.	1921	12.1		14.3	
		1922	41.8		32.0	
		1923	26.5		23.9	
		1924	47.2		51.3	
		Aver.		31.9		30.4
	Duluth, Minn.	1922	20.0		18.3	
		1923	22.7		21.4	
		Aver.		21.4		19.9
	Grand Rapids, Minn.	1924	68.6		56.9	

For further information see bulletin by Hayes and Garber (8).

WEBSTER—Reg. No. 239

Webster (C. I. No. 3780) was one of a collection introduced in 1912 by the United States Department of Agriculture through the Bureau of Applied Botany, Leningrad, Russia, from Russian Turkestan. Among a large number of wheats in the collection, this variety was most resistant to stem rust and produced the best yields in experiments at the Highmore, S. Dak., station. The variety has been used for crossing with Kota and other varieties by E. S. McFadden, of Webster, S. Dak., for which place the variety was named. The Webster variety was tested for rust resistance in greenhouse experiments at University Farm, St. Paul, Minn., and showed resistance to several forms of stem rust. It also has been found resistant to leaf rust by McFadden and in greenhouse experiments at Purdue University Agricultural Experiment Station, Lafayette, Ind. The Webster variety has awned, fusiform spikes; weak stems; glabrous, brown glumes; and long, hard red kernels. It should follow Red Rock (Reg. No. 181) in the present scheme of classification. The application for registration was made by E. S. McFadden. The rust resistance of the variety during the 5-year period from 1920 to 1925, inclusive, on McFadden's Farm at Webster, S. Dak., is as follows:

Varieties	Stem rust infection						
	1920	1921	1922	1923	1924	1925	Average
Webster (new)	100	trace	trace	75	0	30	34.2
Marquis (standard)	100	50	50	100	1	40	56.8

For further information see McFadden (10) and Stakman, Levine and Griffee (12).

HOPE—Reg. No. 240

Hope (H 49–24; C. I. No. 8178) was developed by E. S. McFadden, of Webster, S. Dak. It is the result of a cross made in 1915 between Vernal emmer and Marquis wheat, and was last selected in 1923. The Hope variety is very resistant both to stem and leaf rust. It also is drought resistant. Because of its strong flexible straw and stiff glumes it is less injured by hail than some other varieties. The Hope variety is awned and has glabrous white glumes and purple stems. It should follow Pioneer (Reg. No. 154) in the present classification. The Hope wheat appears at present to be valuable principally for breeding purposes. It may have commercial value but comparable yields have not yet been obtained. The rust resistance of the Hope variety or its parent line in comparison with Marquis during the six years, 1920 to 1925, inclusive, at Webster, S. Dak., is as follows:

Varieties	Stem rust infection						
	1920	1921	1922	1923	1924	1925	Average
Hope (new)	0[a]	0[a]	0[a]	0	0	0	0
Marquis (standard)	100	50	50	100	1	40	56.8

[a] Parent line.

CERES—Reg. No. 241

Ceres (N. Dak. No. 16006; C. I. No. 6900) was developed at the North Dakota Agricultural Experiment Station by L. R. Waldron, from a hybrid between Marquis (female) and Kota (male) made in 1918. The Ceres variety resulted from a selection known as Ns. 1658 made in 1921. Ceres is awned and should follow Kota in the present scheme of classification. The superior characters of Ceres are resistance to stem rust, early maturity, and high quality. It has been grown for three years at experiment stations in North Dakota, in other spring wheat States and in Canada. It was grown both in rod-row nurseries and in field plat experiments. The plat data for Ceres, Kota and Marquis at Fargo, and the average data for Ceres in comparison with the average of its parents at all experiment stations where comparable tests have been made, are as follows:

Varieties	1923	1924	1925	Average
Fargo (plats)				
Ceres (new)	32.2	45.3	29.3	35.6
Kota (standard)	29.2	40.1	22.2	30.5
Marquis (standard)	25.5	39.5	23.9	29.6
All stations	(5 trials)	(15 trials)	(44 trials)	
Ceres (new)	32.2	45.3	33.3	36.9
Average of parents	27.4	39.8	24.6	30.6

For further information see Waldron (16).

NODAK—Reg. No. 242

Nodak (C. I. No. 6519) durum wheat was developed in cooperative experiments of the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and the North Dakota Agricultural Experiment Station at the Dickinson Substation, Dickinson, N. Dak. It is the result of a selection made from Kubanka, C. I. 1440, in 1915, by Ralph W. Smith. Nodak is similar in appearance to Kubanka and should follow Kubanka No. 8 (Reg. No. 216) in the present scheme of classification. The superior characters of Nodak are resistance to stem rust and drought, high yield, and its good quality for semolina. Nodak has been distributed for commercial growing in North Dakota since 1923, and has been under experiment for 10 years at the Dickinson Substation and for shorter periods at other stations in North Dakota, and adjoining states. The annual and average plat yields of the variety at the Dickinson Substation for the six-year period 1920 to 1925, inclusive, in comparison with Kubanka, C. I. No. 1440, are as follows:

Varieties	1920	1921	1922	1923	1924	1925	Average
Nodak (new)	24.8	6.5	34.9	23.8	21.0	15.5	21.1
Kubanka (standard)	23.6	7.1	31.4	22.9	20.0	14.5	19.9

For further information see bulletin by Smith, Waldron and Clark (11).

RELIANCE—Reg. No. 243

Reliance (C. I. No. 7370) was developed by the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, in cooperation with the Oregon, California, Montana, North Dakota, and Minnesota experiment stations. It is the result of a hybrid between Kanred (female) and Marquis (male). The cross was made in 1917 by F. J. Schneiderhan at the Sherman County Branch Station, Moro, Oreg. The selection from which Reliance descended was made in 1920 by J. A. Clark, at the United States Plant Introduction Station, Chico, Calif. Reliance is a bearded, white glabrous glumed variety and should follow Preston (Reg. No. 152) in the classification. The superior characters of Reliance are resistance to stem rust, plant vigor, strong stems, and high yield. Reliance has been tested for five years in nursery and plat experiments at numerous experiment stations in the northern spring wheat area of the United States. The yields obtained from these experiments in comparison with Marquis, one of its parents, and the principal commercial variety in the area, are as follows:

Station	Year	Nursery Reliance	Nursery Marquis	Plats Reliance	Plats Marquis
Moccasin, Mont.	1921	32.1	30.9		
	1922	23.8	22.5		
	1923	44.1	35.8		
	1924	47.8	36.9	31.1	32.0
	1925	20.8	19.5	24.3	22.4
	Aver.	33.7	29.1	27.7	27.2
Dickinson, N. Dak.	1922	21.7	18.9		
	1923	16.5	13.2		
	1924	16.2	18.2	23.9	23.3
	1925	18.3	15.4	20.1	17.4
	Aver.	18.2	16.4	22.0	20.4
Mandan, N. Dak.	1924	25.0	22.2	25.6	25.4
	1925	26.0	26.5	16.0	15.2
	Aver.	25.5	24.4	20.8	20.3
Fargo, N. Dak.	1923	37.0	34.6		
	1924	43.1	38.4		
	1925	22.2	24.3		
	Aver.	34.1	32.4		
St Paul, Minn.	1922	48.1	36.0		
	1923	32.9	31.0		
	1924	29.9	26.9		
	1925	35.2	35.4		
	Aver.	36.3	32.3		
Waseca, Minn.	1923	26.3	22.2		
	1924	18.6	23.5		
	1925	18.0	19.1		
	Aver.	21.0	21.6		
Crookston, Minn.	1923	15.1	15.8		
	1924	23.1	22.1		
	1925	18.8	22.8		
	Aver.	19.0	20.2		
Morris, Minn.	1924	38.1	34.1		
	1925	17.0	17.8		
	Aver.	27.6	26.0		
Akron, Colo.	1922	6.5	6.3		
	1923	9.7	4.6		
	Aver.	8.1	5.5		
North Platte, Nebr.	1924	32.5	31.4		
	1925	7.2	11.2	14.6	15.8
	Aver.	19.9	21.3		
Redfield, S. Dak.	1925			10.3	11.9
Sheridan, Wyo.	1925			42.2	38.1

For further information see Circular by Clark, Martin and Stakman (4).

KARMONT—Reg. No. 244

Karmont (C. I. No. 6700) was developed in the cooperative experiments of the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, and the Montana Agricultural Experiment Station at the Judith Basin Substation, Moccasin, Mont. It is the result of head selection No. 30 made from Kharkof, C. I. 1583, in 1911, by E. L. Adams. The value of the variety was determined by experiments conducted by Ralph W. May, who applied for its registration. The Karmont variety is similar in appearance to Kharkof and Turkey wheats and should follow Montana No. 36 (Reg. No. 146) in the classification. The superior characters of Karmont are its yielding ability under Montana conditions. It has been grown in nursery and plat experiments at the Judith Basin Substation during 14 years, and has been grown commercially in Montana since the fall of 1921. During the past eight years the plat experiments have been grown each year in four systematically replicated plats. The data for Karmont in comparison with those for Kharkof (C. I. No. 1583) are as follows:

Varieties	1918	1919	1920	1921	1922	1923	1924	1925	Average
Karmont (new)	28.3	6.3	26.5	19.5	35.0	34.6	39.1	25.5	26.9
Kharkof (standard)	25.4	5.3	21.9	16.3	35.9	35.3	36.9	26.2	25.4

For further information see bulletin by Clark and Martin (1, p. 23).

NEWTURK—Reg. No. 245

Newturk (C. I. No. 6935) was developed in the cooperative experiments of the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, and the Oregon and Montana agricultural experiment stations. It is the result of a hybrid between Newton, C. I. 5300 (female) and Turkey, C. I. 1558 (male) made in 1916 at the Sherman County Branch Station, Moro, Oreg. The F_2 and F_3 generations of this cross were grown at Chico, Calif., where several hundred awnless selections were made by J. A. Clark. Some of these were sent to the Judith Basin Substation, Moccasin, Mont., for seeding in the fall of 1920. One of these selections known as 166 B1–6, proved promising and was named Newturk. The Newturk is a tip-awned or awnletted strain of hard red winter wheat and should follow Alton (Reg. No. 55) in the classification. Its superior characters are high yield, resistance to shattering, and good quality for milling and bread-making. Seed of the Newturk variety was increased for commercial growing at the Moccasin station in 1925. Ralph W. May applied for its registration. The annual and average yields of Newturk, in nursery and plat experiments at Moccasin in comparison with comparable yields of Kharkof (164A), used as a parent in another cross, are as follows:

Varieties	1920	1921	1922	1923	1924	Average
Newturk (new)........	46.9	27.3	43.5	37.4	38.8	38.8
Kharkof (standard).....	45.4	27.9	41.9	29.8	35.2	36.0

For further information see circular by Clark, Martin and Parker (3).

AKRONA—Reg. No. 246

Akrona (C. I. No. 6881) was developed by the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, at the Akron Field Station, Akron, Colo. It is the result of a selection from Arnautka, C. I. 1493, made in 1912 by Clyde McKee. The value of this particular selection (1493–7–12) was determined in nursery and plat experiments conducted by F. A. Coffman, who applied for its registration. The Akrona variety should follow the Monad (Reg. No. 212) in the classification. Its superior characters are early maturity, high yield under Colorado conditions, and high gasoline color value, indicating its superiority for the manufacture of macaroni. The variety has been increased and distributed for commercial growing in Colorado. Yields obtained at the Akron Field Station in replicated plat experiments during the five years from 1920 to 1924, inclusive, in comparison with those of Arnautka, the parent variety, are as follows:

Varieties	1920	1921	1922	1923	1924	Average
Akrona (new)..........	20.4	10.2	10.2	17.2	0	11.6
Arnautka (standard)....	15.2	7.8	9.2	15.0[a]	0	9.4

[a] Kubanka, C. I. 1440, substituted.

For further information see bulletin by Coffman (6, p. 34).

MOSIDA—Reg. No. 247

Mosida (Idaho No. 156; C. I. No. 6688) was developed by the University of Idaho from a cross made at the Colorado Agricultural Experiment Station, between Fultzo-Mediterranean (female) and Turkey (male) in 1916. The crossed material was taken to the Idaho station by G. S. Ray. The Mosida variety resulted from a selection made at the Idaho station in 1918. H. W. Holbert, of the Agronomy Department of the University of Idaho, applied for registration. Mosida is an awnletted or tip-awned variety of hard red winter wheat and should follow Huston (Reg. No. 54) in the classification. The superior characters of Mosida are better than average bunt resistance, good strength of straw, and high yield. It is adapted to the cut-over sections of northern Idaho. The Mosida variety has been distributed for commercial growing in Idaho by the Idaho station. The annual and average yields in field plat experiments (duplicated 1/40th-acre plats) during the five-year period, 1920 to 1924, inclusive, together with those of Triplet, the best yielding wheat at the Idaho station, are as follows:

Varieties	1920	1921	1922	1923	1924	Average
Mosida (new)	61.7	67.0	49.5	79.8	56.3	62.9
Triplet (standard)	65.6	74.3	44.3	78.0	61.0	64.6

RIDIT—Reg. No. 248

Ridit (Wash. No. 2324; C. I. No. 6703) was developed by the Washington Agricultural Experiment Station, Pullman, Wash. It is the result of a hybrid between Turkey (female) and Florence (male) made in 1915 by E. F. Gaines. A selection made in 1919 resulted in the Ridit variety. It is an awnletted or tip-awned variety of hard red winter wheat and should follow Alton (Reg. No. 55) in the present classification. The superior characters of Ridit are resistance to bunt or stinking smut, resistance to shattering, good yields, and superior milling qualities. It has been grown in nursery and plat experiments for yield and bunt resistance for the seven-year period from 1919 to 1925, inclusive. It was distributed for commercial growing in Washington in 1923. The results obtained from Ridit in comparison with those from Hybrid 128, the best yielding wheat at Pullman, are as follows:

Varieties and factors	1919	1920	1921	1922	1923	1924	1925	Average
Yield (bu. per acre)								
Ridit (new)	36.9	52.5	42.0	31.7	45.1	33.2	41.6	40.4
Hybrid 128 (standard)	46.0	49.0	48.5	32.0	44.8	34.2	49.1	43.4
Per cent bunt (inoculated seed)								
Ridit	0	0	3[a]	0	.01	0	0	Trace
Hybrid 128	98	81	94	91	80	18	55	74

[a] One bunted plant— probably a mixture.

For further information concerning the development of Ridit see Gaines (7).

SHERMAN—Reg. No. 249

Sherman (C. I. No. 4430) was developed in the cooperative experiments of the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, and the Oregon Agricultural Experiment Station at the Sherman County Branch Station, Moro, Oreg. It is the result of a selection from Crimean made by J. A. Clark at Moccasin, Mont., in 1915. Experiments at the Moro, Oreg., station, starting in 1918, determined that the variety is very resistant to bunt, or stinking smut. Because of this resistance to bunt and because of fair yields and certain desirable bread-making qualities, Sherman is being used in wheat breeding experiments at several experiment stations. Sherman is a bearded, white glabrous-glumed, semi-hard winter wheat and should precede Minturki (Reg. No. 139) in the present classification. The annual and average yields of Sherman grown in triplicate 1/20th acre plats at the Moro station during the four years from 1922 to 1925, inclusive, in comparison with those of Kharkof, are as follows:

Varieties	1922	1923	1924	1925	Average
Sherman (new)	20.7	35.2	16.8	30.0	25.7
Kharkof (standard)	17.1	35.3	20.3	27.4	25.0

For further information see bulletin by Stephens and Woolman (14, p. 39).

REGAL—Reg. No. 250

Regal (C. I. No. 7364) was developed at the Sherman County Branch Station, Moro, Oreg. It is the result of a selection made by H. M. Woolman in 1921, at Corvallis, Oreg., from Turkey, C. I. 1571C. D. E. Stephens, superintendent of the Moro station, who largely determined the value of the selection, applied for its registration. The superior characters of this variety are resistance to bunt or stinking smut, yielding ability, and purple stems, which latter is an advantage in maintaining purity for seed certification. It should follow Bacska (Reg. No. 151) in the classification. The Regal variety was increased for commercial distribution from the Moro station in 1926. The annual and average yields of Regal in triplicate 1/20th acre plats during the three years 1923 to 1925, inclusive, in comparison with those of Kharkof, are as follows:

Varieties	1923	1924	1925	Average
Regal (new)	40.7	17.4	28.0	28.7
Kharkof (standard)	35.3	20.3	27.4	27.7

WHITE ODESSA—Reg. No. 251

White Odessa (C. I. No. 4655) was developed in the cooperative experiments of the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, and the Oregon Experiment Station at the Sherman County branch station, Moro, Oreg. It is the result of a field selection made in the Cache Valley of Utah, in 1915. In experiments at the Moro station, starting in 1918, it has been found to be resistant to bunt or stinking smut and also to be a high-yielding variety. It is similar in appearance to Odessa except in having white kernels. The superior characters of White Odessa are resistance to bunt, drought resistance, and good yields. It should follow Kofod (Reg. No. 68) in the present scheme of classification. The annual and average yields of White Odessa in triplicate 1/20th acre plats at the Moro, Oreg., station for the four years 1922 to 1925, inclusive, in comparison with Kharkof, are as follows:

Varieties	1922	1923	1924	1925	Average
White Odessa (new)	23.0	35.9	18.5	28.0	26.4
Kharkof (standard)	17.1	35.3	20.3	27.4	25.0

For further information see Stephens and Woolman (14).

ONAS—Reg. No. 252

Onas (C. I. No. 6221) was introduced by the United States Department of Agriculture from Tuela, Saddleworth, South Australia, in 1918. It was originally developed through hybridization by F. Coleman, Federation being one parent.

The value of this wheat for California conditions has been determined in the cooperative experiments of the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, and the California Agricultural Experiment Station. V. H. Florell, who conducted the experiments at University Farm, Davis, Calif., applied for its registration. Its superior characters are strong stems, high yielding capacity, and good milling and bread-making qualities. Onas should follow Bunyip (Reg. No. 15) in the classification. Onas was increased at the Davis station in 1923 and distributed for commercial growing. The annual and average yields of Onas grown at the Davis station in five systematically replicated 50th-acre plats during the four-year period from 1922 to 1925, inclusive, in comparison with Pacific Bluestem, the principal commercial variety of that state, are as follows:

Varieties	1922	1923	1924	1925	Average
Onas (new) .	81.9	70.8	48.1	40.6	60.4
Pacific Bluestem (standard).	67.0	59.2	41.8	32.1	50.0

For further information concerning the introduction of Onas wheat see Clark, Stephens and Florell (5).

SHEPHERD—Reg. No. 253

Shepherd (C. I. No. 6163) was developed in the cooperative experiments of the Office of Cereal Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture, and the Plant Breeding Department of Cornell University. The original selection from the variety known as Tennessee Fultz was made at Cornell University Agricultural Experiment Station, Ithaca, N. Y., in 1912, by C. E. Leighty. The superior characters of the variety are resistance to flag smut and rosette, and high-yielding ability. It should follow Ashland (Reg. No. 49) in the classification. Shepherd, tested for resistance to flag smut during a five-year period at Granite City, Ill., was found immune, as compared with a 10 to 30 percent infection in Harvest Queen. It also was found immune from rosette. Shepherd was increased and has been grown commercially in the areas of Illinois infected with these diseases, since 1923. The yields of Shepherd in plat experiments at the Arlington Experiment Farm, Va., during eight years from 1918 to 1925, inclusive, in comparison with Purplestraw, the best yielding variety at that station, are as follows:

Varieties	1918	1919	1920	1921	1922	1923	1924	1925	Average
Shepherd (new).	37.2	36.0	29.4	18.7	32.6	31.9	23.6	31.2	30.1
Purplestraw (standard) . .	36.3	27.4	30.7	19.8	31.2	33.0	29.9	31.3	30.0

For further information see Webb, Leighty, Dungan and Kendrick (17).

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REGISTRATION OF VARIETIES AND STRAINS OF OATS[1]

T. R. STANTON, FRED GRIFFEE, and W. C. ETHERIDGE[2]

Most of the so-called varieties of oats grown commercially in the United States at the present time are simply strains or races (jordanons) of a relatively few distinct botanical types. To differentiate these numerous strains by the use of minute, obscure and otherwise unsatisfactory, morphologic characters is not practicable and would result in still greater confusion of varieties and varietal nomenclature than already exists. Because of this situation a registration system has been established which is based on physiological differences as shown by performance. It is well known that certain strains may

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[1] Received for publication September 15, 1926.

[2] Members of the 1926 subcommittee for the Registration of Oat Varieties.

be similar or identical morphologically, but differ markedly in yielding power. An outstanding, high-yielding strain of proved performance seems entitled to recognition by registration regardless of the fact that a strain similar morphologically but inferior in yield is already registered.

STANDARD VARIETIES

As a basis for starting the registration system of the American Society of Agronomy those agronomic varieties which have become recognized because of their agricultural importance, have been registered. These basic varieties usually are sufficiently distinct morphologically so that little trouble should arise in attempting to identify them.

The following are the 42 standard varieties of recognized agricultural importance which have been registered, together with the registration number assigned to each:

Group and Varietal Name	Reg. No.
Red Rustproof oat (*Avena byzantina*)	
Burt	1
Coastblack	2
Fulghum (King of Etheridge)	3
Red Rustproof	4
Common oat (*A. sativa*)	
Belyak	5
Black Diamond	6
Black Mesdag	7
Black Norway	8
Canadian	9
Culberson	10
Danish Island	11
Early Champion	12
Early Mountain	13
Garton No. 5 (Garton No. 691 of Etheridge)	14
Garton 473	15
Golden Rain (Golden Drop of Etheridge)	16
Gothland (Early Gothland of Etheridge)	17
Green Russian	18
Irish Victor	19
Japan (Japan Selection of Etheridge)	20
Joanette	21
Kherson (Sixty-Day)	22
Lincoln	23
Madrid (C. I. No. 603 of Etheridge)	24
Monarch	25
North Finnish	26
Old Island Black	27
Awnless Probsteier	28
Scottish Chief	29
Silvermine	30
Swedish Select	31
Tobolsk	32
Victor	33
Winter Turf	34
Common side oat (*A. sativa orientalis*)	
Black Tartar (Black Tartarian of Etheridge)	35
Garton Gray	36
Golden Giant	37
Green Mountain	38
Sparrowbill	39
Storm King	40
Tartar King	41
White Tartar	42

Several distinct botanical or taxonomic varieties of no definite agricultural importance or value are excluded from the registration list. It is realized that these varieties are of interest taxonomically and some possess special value in plant breeding.

Of the 42 varieties named as standard taxonomic types, Etheridge (4)[3] has described all except Coastblack. The description given by Etheridge (4, p. 127) under *Avena sterilis nigra* and by Marquand (7, p. 35) under the name Black Algerian, apply to Coastblack, except that the plant is more prostrate in early growth and is much later in maturity. Etheridge (4, p. 145) has described Sixty-Day as a white oat. However, Warburton and Stanton (10), who present a complete history and description of the original Kherson and Sixty-Day oats, consider them identical and as having yellow kernels.

IMPROVED VARIETIES AND STRAINS

The following new and improved sorts have been approved for registration primarily on the basis of performance. They do not represent definite botanical varieties in all cases, but for the most part are strains of some of the standard varieties.

Group and Varietal Name	Reg. No.	Group and Varietal Name	Reg. No.
Spring Oats		Midseason White:	
Early Black:		Colorado No. 37	53
Colburt	43	Comewell	54
Early Yellow:		Empire	55
Richland (Iowa No. 105)	44	Forward	56
State Pride	45	Idamine	57
Early White:		Ithacan	58
Albion (Iowa No. 103)	46	Minota	59
Gopher	47	Standwell	60
Iowar	48	Upright	61
White Cross	49	Wisconsin Wonder	62
Midseason Gray:		Winter Oats	
Cornellian	50	Midseason Black:	
Midseason Yellow:		Tech	63
Iogren	51	Midseason Yellow:	
Markton	52	Lee	64

Approval of registration is based on the description and record of each of these varieties, which are summarized here for the benefit of those not familiar with them.

COLBURT— Reg. No. 43

Colburt (C. I. No. 2019) originated as a pure line from Burt, C. I. No. 293. The plant selection was made by Wilson G. Shelley at the Akron (Colo.) Field Station in 1911. It subsequently was developed by the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, in cooperation with the Colorado Agricultural Experiment Station. Others who had part in its development were Clyde McKee, Charles H. Clark, George A. McMurdo, and F. A. Coffman. Coffman (3) has published brief notes on its history and applied for its registration. Colburt is an early black common oat morphologically

[3] Reference by number is to "Literature Cited," p. 946.

similar to Monarch. Its superior characters are early maturity, drought escapement, and high test weight per bushel. It has been tested for 13 years in quadruplicated fiftieth-acre plats at Akron. The acre yields in bushels of Colburt and of Kherson in the five-year period from 1920 to 1924, inclusive, are as follows:

Varieties	1920	1921	1922	1923	1924	Average
Colburt (New)	32.0	30.5	28.2	42.4	7.2	28.1
Kherson (Standard) ..	39.2	24.7	25.7	34.8	6.6	26.2

Colburt is grown commercially to some extent in northeastern Colorado.

RICHLAND—Reg. No. 44

Richland (C. I. No. 787) is a pure line from Kherson. The original plant selection (Iowa No. 105) was made at Ames, Iowa, in 1906 by L. C. Burnett. It was developed cooperatively by the Iowa Agricultural Experiment Station and the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Richland was first distributed to farmers in 1914. Burnett applied for its registration. Richland is an early yellow common oat of the Kherson type. It differs from Kherson only in having a slightly shorter straw. The superior characters of Richland are high yield, resistance to stem rust of oats, and adaptability for growing on rich soils without lodging. It has been tested at Ames for 15 years in replicated field plats. The acre yields in bushels of Richland as compared with Kherson for the thirteen years 1910 to 1919 and 1921 to 1923, inclusive, are as follows:

Varieties	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1921	1922	1923	Average
Richland (New)	70.0	44.8	83.7	55.6	62.8	59.3	53.3	64.3	55.6	47.5	37.2	65.0	78.1	59.8
Kherson (Std.)	62.2	38.1	65.6	62.8	55.3	49.7	53.8	65.0	62.5	41.9	25.9	67.1	78.7	56.0

For more complete information on Richland see Burnett, Stanton and Warburton (2).

STATE PRIDE—Reg. No. 45

State Pride (C. I. No. 1154) originated at Madison, Wis., in 1907 as a pure line from the Kherson variety. It was selected by R. A. Moore, of the Department of Agronomy, University of Wisconsin, which institution developed and distributed it. Application for its registration was made by B. D. Leith, for the University of Wisconsin. State Pride is an early yellow common oat similar to Kherson but it grows decidedly taller. The superior characters of State Pride are high yield, earliness, and adaptability to fertile soil. It fills well even when lodged. It has been grown for fourteen years in twentieth acre plats in the experiments at Madison. For the five years from 1920 to 1924, inclusive, the annual and average acre yields in bushels of State Pride as compared with Swedish Select (Wisconsin No. 5) are as follows:

Varieties	1920	1921	1922	1923	1924	Average
State Pride (New)	82.0	46.9	65.0	31.3	65.7	58.2
Swedish Select, Wisconsin No. 5 (Standard)	53.8	21.7	50.6	48.3	55.6	46.0

For further information see Leith and Delwiche (5).

ALBION—Reg. No. 46

Albion (C. I. No. 729) originated as an individual plant selection (Iowa No. 103) from Kherson, made by L. C. Burnett at Ames, Iowa, in 1906. It was developed cooperatively by the Iowa Agricultural Experiment Station and the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Albion was first distributed to farmers in 1913. Burnett applied for its registration. Albion is an early white common oat. It differs from Kherson primarily in having white kernels and usually more awns. The superior characters are its earlier maturity and white kernels. It has been tested for 13 years at Ames in replicated plats, where it has been inferior in yield to Kherson, the parent variety. The acre yields in bushels for these years are as follows:

Varieties	1910	1911	1912	1913	1914	1915	1916
Albion (New)...	55.4	40.6	53.7	63.7	55.6	41.6	46.1
Kherson (Std.)..	62.2	38.1	65.6	62.8	55.3	49.7	53.8
Varieties	1917	1918	1919	1921	1922	1923	Average
Albion (New)...	73.7	48.7	32.2	37.4	58.7	68.7	52.0
Kherson (Std.)..	65.0	62.5	41.9	25.9	67.1	78.7	56.0

In tests on Iowa farms, however, Albion has exceeded Kherson in yield. The results of 66 such tests conducted in the years 1913 to 1917, nclusive, are as follows:

Varieties (Year).......	1913	1914	1915	1916	1917	Average
(Number of tests)	12	6	15	21	12	
Albion (New)..........	49.8	47.6	60.7	49.7	61.2	53.8
Kherson (Standard).....	46.9	44.0	58.2	46.2	58.7	50.8

For more complete information on Albion see Burnett, Stanton and Warburton (2).

GOPHER—Reg. No. 47

Gopher (C. I. No. 2027) is a pure line selection (Minnesota No. 674) from Sixty-Day, made at University Farm, St. Paul, Minn., in 1917, by the Minnesota Agricultural Experiment Station which institution applied for registration. Gopher is an early white common oat similar to Albion, but produces a slightly plumper kernel. Its superior characters are early maturity, stiff straw, high-yielding power, and white kernels. It has been tested for several years in three or four systematically distributed plats of 3 rod-rows each, with only the center row used for yield determination, and in three or four systematically replicated and distributed fortieth-acre plats with border drill rows removed. The annual and average acre yield in bushels of Gopher and Sixty-Day oats in Minnesota at University Farm in the four-year period from 1918 to 1921, inclusive, and at Crookston, Morris, and Waseca in the three-year period from 1919 to 1921, inclusive, are shown in the following table:

	Year	Acre yield (bushels)			
Location of station	of	Sixty-Day (Commercial)		Gopher	
	test	Annual	Average	Annual	Average
University Farm, St. Paul......	1918	75.7	..	81.3	..
	1919	80.1	..	70.4	..
	1920	61.7	..	67.6	..
	1921	71.6	72.3	68.2	71.9

Crookston.......	1919	20.8	..	14.6	..
	1920	40.0	..	51.8	..
	1921	15.1	25.3	15.6	27.3
Morris.........	1919	39.6	..	41.7	..
	1920	26.5	..	25.0	..
	1921	56.6	40.9	64.1	43.6
Waseca.........	1919	46.0	..	50.2	..
	1920	50.0	..	64.9	..
	1921	39.1	45.0	42.1	52.4

Average acre yields of Gopher, Iowar, and Albion (Iowa No. 103) oats expressed in percentages obtained at five experiment stations in southern and central Minnesota in the three-year period from 1920 to 1922, inclusive, are shown in the following table:

Variety	Minn. No.	Yields in per cent of Gopher				
		University Farm	Lewiston	Waseca	Blue Earth	Morris
Gopher......	674	100.0	100.0	100.0	100.0	100.0
Iowar.......	670	90.3	94.8	82.5	105.1	88.8
Albion (Iowa No. 103)...	531	96.3	89.6	82.8	82.8	81.5

For further data on the Gopher oat see Arny and Hayes (1).

IOWAR—Reg. No. 48

Iowar (C. I. No. 847) is a pure-line selection (Iowa No. 779) from Kherson which was made in 1910 by L. C. Burnett of the Iowa Agricultural Experiment Station. It was developed in the cooperative experiments conducted by that Station and the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Iowar was first distributed to farmers in 1919. Burnett applied for its registration. Iowar is an early white common oat similar to Albion, but has a little coarser and taller straw and ripens two or three days later. Its superior characters are high-yielding power, white kernels, and sufficiently tall straw for convenience in harvesting. Iowar has been tested nine years at Ames in replicated field plats. The plats of Iowar were destroyed by storms in 1919 and no experiments were conducted in 1920. The annual and average acre yields in bushels of the Iowar as compared with Kherson in the six years 1916 to 1918 and 1921 to 1923, inclusive, are as follows:

Varieties	1916	1917	1918	1921	1922	1923	Average
Iowar (New)...	56.7	57.5	62.5	41.2	60.6	87.8	61.1
Kherson (Std.)..	53.8	65.0	62.5	25.9	67.8	78.7	59.0

For more complete information on Iowar see Burnett, Stanton, and Warburton (2).

WHITE CROSS—Reg. No. 49

White Cross (C. I. No. 2026) originated as a selection (Wisconsin No. 19) from a Big Four (Wisconsin No. 2) x Sixty-Day cross made in 1911 by B. D. Leith. The variety was developed and distributed by the Department of Agronomy, University of Wisconsin, Madison. It was last selected in 1916. Application for its registration was made by B. D. Leith for the Department. White Cross is an early white common oat similar to Albion, except that it has a taller culm and a little larger kernel. Its superior characters are high yield, earliness, tall straw, and adaptability for growing on light soils. White Cross has been tested for eight years in twentieth-acre plats at Madison. The annual and average acre yields in bushels obtained during the five-year period from 1920 to 1924, inclusive, from White Cross as compared with Swedish Select (Wisconsin No. 5), are as follows:

Varieties	1920	1921	1922	1923	1924	Average
White Cross (New).....	67.2	41.9	58.2	37.0	52.7	51.4
Swedish Select, Wisconsin No. 5 (Standard).....	53.8	21.7	50.6	48.3	55.6	46.0

For further information on White Cross see Leith and Delwiche (5).

CORNELLIAN—Reg. No. 50

Cornellian (C. I. No. 1242) is a pure line from a variety with equilateral panicles to which the name Canada Cluster had been applied. The head selection was made at Ithaca, N. Y., in 1912. It was developed by the Department of Plant Breeding, Cornell University, in cooperation with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. It was first distributed in 1920. Application for its registration was made by the Department of Plant Breeding, Cornell University. Cornellian is a midseason common oat with tall straw and slender, awnless gray kernels. Its superior characters are low percentage of hull and high yield. Cornellian has been ested for thirteen years at Ithaca in replicated rod rows and plats. The acre yields in bushels of Cornellian as compared with Silvermine for the five years, 1921 to 1925, inclusive are as follows:

Varieties	1921	1922	1923	1924	1925	Average
Cornellian (New).......	63.9	61.4	54.2	97.6	89.4	73.3
Silvermine (Standard)...	52.1	52.3	43.0	80.4	82.6	62.1

For additional information on Cornellian see Love, Stanton and Craig (6).

IOGREN—Reg. No. 51

Iogren (C. I. No. 2024) was developed from a single head (Iowa No. 840) of the Green Russian variety obtained from W. Eral, Pocahontas, Iowa. It was grown in a head row by L. C. Burnett at the Iowa Agricultural Experiment Station in 1911, and subsequently developed by that station in cooperation with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Burnett applied for its registration. It was distributed to farmers in 1922. Iogren is a midseason yellow common oat and is a typical Green Russian oat. Its superior characters are high-yielding power and relative freedom from stem rust. Iogren has been tested at Ames, Iowa, for nine years. The annual and average acre yields in bushels of the Iogren as compared with the Green Russian parent and Kherson obtained at Ames in the seven years indicated are as follows:

Varieties	1916	1917	1918	1919	1921	1922	1923	Average
Iogren (New)........	64.4	62.5	82.5	50.0	40.6	65.0	84.7	64.2
Green Russian (Std.)..	53.6	50.0	74.4	45.9	37.8	57.5	74.7	56.3
Kherson (Standard)...	53.8	65.0	62.5	41.9	25.9	67.8	78.7	56.5

For more complete information regarding Iogren see Burnett, Stanton and Warburton (2).

MARKTON—Reg. No. 52

Markton (C. I. No. 2053) originated as a pure line from an unnamed oat (C. I. No. 357) obtained by the late M. A. Carleton from the exhibit of Louis Dreyfus & Company at the Louisiana Purchase Exposition. The original head was selected in 1911 by H. J. C. Umberger at the Sherman County Branch Station, Moro, Oreg. The variety was subsequently developed and distributed by this station under the supervision of D. E. Stephens, in cereal experiments conducted cooperatively by the Oregon Agricultural Experiment Station and the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Its immunity from covered smut was discovered by E. F. Gaines, Agricultural Experiment Station, Pullman, Wash. Application for registration of Markton was made by D. E. Stephens. Markton is a midseason, midtall common oat with culms hairy near the nodes, large drooping panicles, and rather long, slender to midplump, yellowish-white kernels. The lower floret of the spikelet usually is awned. It is a rather distinct variety. The superior characters of Markton are early maturity, high yield, immunity from the smuts of oats, thin hull, and excellent milling quality. Markton has been tested at Moro for eleven years in duplicated or triplicated twentieth-acre plats. The annual and average acre yields in bushels of the Markton and Sixty-Day in the five years 1920 to 1924, inclusive, are as follows:

Varieties	1920	1921	1922	1923	1924	Average
Markton (New)	44.1	46.7	32.5	86.3	35.0	48.9
Sixty-Day (Standard)	35.9	45.6	23.5	80.3	31.4	43.3

For more complete information on Markton see Stanton, Stephens and Gaines (9).

COLORADO—Reg. No. 53

Colorado No. 37 (C. I. No. 1640) was selected in 1900 from a field of commercial oats on the farm of P. A. Amiss, at La Gratin, in the San Luis Valley of southwestern Colorado, by A. H. Danielson, of the Agronomy Section, Colorado Agricultural College, which institution developed and distributed it. Alvin Kezer of the same institution applied for its registration. Colorado No. 37 is a midseason white common oat similar to Swedish Select, except that it has decidedly fewer awns and a little shorter culm. The superior characters are high yield, stiff straw, and awnless kernels. It has been tested in small replicated plats for 14 years at Fort Collins. Colo. In the five-year period from 1920 to 1924, inclusive, the acre yields in bushels of Colorado No. 37 as compared with Silvermine at Fort Collins were as follows:

Varieties	1920	1921	1922	1923	1924	Average
Colorado No. 37 (New) .	109.0	107.0	86.5	116.8	79.8	101.8
Silvermine (Standard) .	102.9	92.1	94.6	110.0	81.5	96.2

This improved strain has become fairly widely distributed for growing under irrigation in the western United States.

COMEWELL—Reg. No. 54

Comewell (C. I. No. 1317) originated as a head selection from the Welcome variety made at Shirley, Ill., in 1904. It was tested and developed by the Department of Plant Breeding, Cornell University, Ithaca, N. Y., in cooperation with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. It was first distributed to farmers in 1912. Application for its registration was made by the Department of Plant Breeding, Cornell

University. Comewell is a midseason white common oat of the Silvermine type. Its superior characters are high test weight per bushel and high yield. It has been tested at Ithaca, N. Y., for fifteen years in replicated rod rows and plats. The acre yields in bushels of Comewell and of Silvermine in the five-year period from 1921 to 1925, inclusive, are as follows:

Varieties	1921	1922	1923	1924	1925	Average
Comewell (New).......	45.5	52.7	51.1	100.3	82.7	66.5
Silvermine (Standard)...	52.1	52.3	43.0	80.4	82.6	62.1

For further information on Comewell see Love, Stanton and Craig (6).

EMPIRE—Reg. No. 55

Empire (C. I. No. 1974) originated as a head selection from Big Four, a fairly well-known commercial variety. It was selected in 1912 at Ithaca, N. Y., by the Department of Plant Breeding, Cornell University, and developed by the same institution in coperation with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Empire was first distributed to farmers in 1918. Application for its registration was made by the Department of Plant Breeding, Cornell University. It is a midseason white common oat of the Silvermine type. The superior characters of Empire are its high test weight per bushel and high-yielding power. It has been tested for thirteen years in replicated rod rows and plats at Ithaca, N. Y. The annual and average acre yields in bushels of the Empire and Silvermine in the five-year period from 1921 to 1925, inclusive, are as follows:

Varieties	1921	1922	1923	1924	1925	Average
Empire (New).........	50.1	52.7	44.5	101.4	79.7	65.7
Silvermine (Standard)...	52.1	52.3	43.0	80.4	82.6	62.1

For additional information on Empire see Love, Stanton and Craig (6).

FORWARD—Reg. No. 56

Forward (C. I. No. 2242) is a pure-line selection from Silvermine. The original plant (Wisconsin No. 1241) was isolated in 1911 and subsequently developed by E. J. Delwiche, Ashland Branch Experiment Station, University of Wisconsin. It was introduced to farmers in 1919 from seed grown on the Ashland station. Application for registration was made by E. J. Delwiche. Forward is a midseason white common oat similar to Silvermine, although it has a slightly longer kernel. Its superior characters are high yield, especially on the red clay belt near Lake Superior, plump kernels, and relative freedom from rust. Forward has been grown in field plats for 13 years at Ashland. The acre yields in bushels obtained in the seven-year period from 1919 to 1925, inclusive, as compared with Swedish Select, are as follows:

Varieties	1919	1920	1921	1922	1923	1924	1925	Average
Forward (New).......	55.6	80.0	39.3	60.9	71.0	48.3	51.0	58.0
Swedish Select, Wisconsin No. 5 (Standard)...	55.6	81.3	28.8	46.1	55.9	47.6	49.5	52.1

For further information see Leith and Delwiche (5).

IDAMINE—Reg. No. 57

Idamine (C. I. No. 1834) is a pure line from a mass strain of Silvermine carried under the name of Funk at the Aberdeen (Idaho) Substation. It was isolated in 1915 by C. W. Warburton and L. C. Aicher, and has been developed and distributed by the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S Department of Agriculture, in cooperation with the Idaho Agricultural Experiment Station. Application for its registration was made by A. E. McClymonds. Idamine is a midseason white common oat of the Silvermine type. Its superior characters are early maturity, strong straw, and very white kernels. It has been tested for five years in duplicated fortieth-acre plats at Aberdeen. The annual and average acre yields in bushels are as follows:

Varieties	1921	1922	1923	1924	1925	Average
Idamine (New)	114.6	92.4	109.9	72.5	156.8	109.2
Swedish Select (Standard)	116.2	90.9	112.5	65.3	141.3	105.2

Idamine is now grown to some extent under irrigation in southern Idaho.

ITHACAN—Reg. No. 58

Ithacan (C. I. No. 2141) was isolated as a head selection from National, a commercial variety, in 1914 by the Department of Plant Breeding, Cornell University, Ithaca, N. Y. It was subsequently developed by that institution in cooperation with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Ithacan was introduced to farmers in 1922. Application for its registration was made by the Department of Plant Breeding, Cornell University. Ithacan is a midseason white common oat of the Silvermine type. The superior characters are high test weight per bushel and high yielding ability. It has been tested at Ithaca for thirteen years in replicated rod rows and plats. The acre yields in bushels obtained from Ithacan and Silvermine in the five years from 1921 to 1925, inclusive, are as follows:

Varieties	1921	1922	1923	1924	1925	Average
Ithacan (New)	55.0	53.1	46.5	106.5	87.9	69.8
Silvermine (Standard)	52.1	52.3	43.0	80.4	82.6	62.1

For more complete information on Ithacan see Love, Stanton and Craig (6).

MINOTA—Reg. No. 59

Minota (C. I. No. 1285) is a pure line from an unnamed commercial variety. The original selection (Minnesota No. 512) was made on a Minnesota farm by the Minnesota Agricultural Experiment Station, probably as early as 1910. This institution subsequently developed and distributed it, and applied for its registration. Minota is a midseason common oat similar to Green Russian, but differs from that variety in having a shorter straw and a yellowish-white kernel. Its superior characters are a rather short, stiff straw combined with midseason maturity and high yield. It has been tested at University Farm, St. Paul, and several other substations in Minnesota for a number of years in three or four systematically replicated and distributed fortieth-acre plats with border drill rows removed and in three or four systematically replicated and distributed plats of three rod rows each with only the center row used for yield determination. The annual and average yields of Minota and Victory oats obtained during the six years from 1919 to 1924, inclusive, at six experiment stations in Minnesota, are shown in the following table:

		Acre yield (bushels)						Average	
Variety	Location of station	1919	1920	1921	1922	1923	1924	1919-1924	1920 1924
Minota (Minn. No. 512) (New)	University Farm, St. Paul	41.6	63.0	47.3	94.0	55.1	52.5	58.9	62.4
	Crookston	16.3	52.4	46.9	61.4	48.4	61.7	47.9	54.2
	Morris	30.7	20.7	30.7	46.4	53.2	73.0	42.5	44.8
	Waseca		81.4	45.8	51.3	85.4	79.2		68.6
	Grand Rapids		56.7	34.9	58.8	71.0	45.9		53.5
	Duluth	48.3	70.5	47.0	53.5	57.3	63.7	56.7	58.4
Victory (Minn. No. 514) (Std.)	University Farm, St. Paul	43.5	64.0	44.1	93.3	51.6	45.3	57.0	59.7
	Crookston	9.3	63.5	32.8	56.8	48.5	66.3	46.2	53.6
	Morris	19.8	31.5	32.8	53.9	59.0	69.5	44.4	49.3
	Waseca		74.2	37.9	56.8	79.5	74.5		64.6
	Grand Rapids	34.3	58.8	33.4	63.3	51.3	44.6	47.6	50.3
	Duluth	53.5	75.3	41.6	61.7	54.4	68.9	59.2	60.4

For further information on Minota see Arny and Hayes (1).

STANDWELL—Reg. No. 60

Standwell (C. I. No. 1975) originated in 1912 at Ithaca, N. Y., as a head selection from Lincoln. It was developed by the Department of Plant Breeding, Cornell University, in cooperation with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Standwell was distributed to farmers in 1918. Application for registration of Standwell was made by the Department of Plant Breeding, Cornell University. It is a midseason white common oat of the Lincoln type. Its superior characters are a rather stiff straw, high quality, and high yield. This strain has been tested for thirteen years in replicated rod rows and plats at Ithaca. In the five-year period from 1921 to 1925, inclusive, the acre yields in bushels of Standwell as compared with Silvermine are as follows:

Varieties	1921	1922	1923	1924	1925	Average
Standwell (New)	52.5	48.4	46.3	107.1	84.6	67.8
Silvermine (Standard) ..	52.1	52.3	43.0	80.4	82.6	62.1

For additional information on Standwell see Love, Stanton and Craig (6).

UPRIGHT—Reg. No. 61

Upright (C. I. No. 2142) originated in 1914 at Ithaca, N. Y., as a pure line from a variety known as American Beauty, obtained from Jefferson County, N. Y. The selection was made and developed by the Department of Plant Breeding, Cornell University, in cooperation with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. It was distributed to farmers in 1918. Application for registration of Upright was made by the Department of Plant Breeding, Cornell University. Upright is a midseason white common oat similar to the variety Scottish Chief. Its superior characters are a stiff straw and high-yielding ability. This oat has been tested for eleven years in replicated rod rows and plats at Ithaca. In the five years from 1921 to 1925, inclusive, the annual and average acre yields in bushels of Upright as compared with Silvermine were as follows:

Varieties	1921	1922	1923	1924	9125	Average
Upright (New)	51.9	42.8	47.6	112.9	85.8	68.2
Silvermine (Standard) ...	52.1	52.3	43.0	80.4	82.6	62.1

For additional information see Love, Stanton and Craig (6).

WISCONSIN WONDER—Reg. No. 62

Wisconsin Wonder (C. I. No. 1645) originated at Madison, Wis., in 1903, as a pure line from a midseason white oat known as White Bonanza grown locally in Wisconsin in 1901. The plant selection (Wisconsin No. 1) was made by R. A. Moore. The Department of Agronomy, University of Wisconsin, developed and distributed it. Application for its registration was made by B. D. Leith for that institution. Wisconsin Wonder is a midseason white common oat. The lower floret of the spikelet usually bears a rather long, twisted and geniculate awn distinctly dark at its base. It resembles Swedish Select in awn characters, but has a more slender kernel and more basal hairs. The superior qualities of Wisconsin Wonder are high yield and a stiff straw. It has been tested for 17 years in twentieth-acre plats at Madison. The annual and average acre yields in bushels obtained in the five years, 1920 to 1924, inclusive, for Wisconsin Wonder as compared with Swedish Select (Wisconsin No. 5) are as follows:

Varieties	1920	1921	1922	1923	1924	Average
Wisconsin Wonder (New)	81.7	24.6	39.7	58.0	51.9	51.2
Swedish Select, Wisconsin No. 5 (Standard).....	53.8	21.7	50.6	48.3	55.6	46.0

For further information on this variety see Leith and Delwiche (5).

TECH—Reg. No. 63

Tech (C. I. No. 947) originated at Blacksburg, Va., in 1908, as a pure line from the Culberson variety. The plant selection (V. P. I. No. 1) was isolated by T. B. Hutcheson, Virginia Agricultural Experiment Station, which institution has been responsible for its development and distribution and application for its registration. Tech is a winter common oat with black kernels. It is similar to the variety described and designated by Etheridge (4) as C. I. No. 606. Tech differs from that variety in ripening somewhat earlier and in having culms rather hairy at the nodes, more awns, and a glabrous second rachilla segment. Its superior characters are high yield, early maturity, and winter resistance. It has been tested for eight years in rod rows at Blacksburg. The annual and average acre yields in bushels of Tech in the five years indicated as compared with Winter Turf (Virginia Gray) are as follows:

Varieties	1916	1918	1919	1921	1924	Average
Tech (New)............	56.2	40.0	48.0	36.7	56.7	47.5
Winter Turf (Standard)..	49.8	35.2	30.4	30.3	27.1	34.6

LEE—Reg. No. 64

Lee (C. I. No. 2042) originated as a selection from a cross of Winter Turf x Aurora made in 1916 by T. R. Stanton at the Arlington Experiment Farm, Rosslyn, Va. It was last selected in 1918 and has been developed by the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture. Application for registration was made by T. R. Stanton. Lee is a winter common oat with rather short, plump, yellowish white kernels. In early growth the plant is similar to Winter Turf, but matures about a week earlier than that variety. It is a rather distinct variety. Its superior characters are high-yielding power, high test weight per bushel, winter resistance, stiff straw, and earlier maturity than Winter Turf. Lee has been tested for five years at the Arlington Experiment Farm in triplicated fortieth-acre plats. The annual and average acre yields in bushels are as follows:

Varieties	1922	1923	1924	1925	1926	Average
Lee (New)	55.0	71.7	74.0	77.8	62.7	68.2
Winter Turf (Standard)	57.0	57.4	70.9	52.0	68.9	61.2

Lee has been distributed to some extent in the more northern sections of the winter oat belt.

For further information on Lee see Stanton (8).

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REGISTRATION OF BARLEY VARIETIES[1]

H. V. Harlan, E. F. Gaines and R. G. Wiggans[2]

The three varieties received so far for registration were produced at the Minnesota Experiment Station and submitted by H. K. Hayes. Hayes appended a tabulation of yields which are not published herewith, as it is desired to publish a shorter statement before the annual meeting when a more definite policy may be evolved. It happens that the chairman was connected with the early work with two of these varieties and some statements of the early history are included herein on his own responsibility, as there was not time to submit the revisions to the originator. It is hoped that this statement of origins will not detract from the later work of Hayes in choosing and increasing these particular sorts.

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[1] Received for publication September 15, 1926.

[2] Members of 1925–26 subcommittee on Registration of Barley Varieties.

MANCHURIA—Minnesota No. 184, Reg. No. 2330

Submitted by H. K. Hayes for registration. This variety is a selection from a stock introduced from Manchuria by the Ontario Agricultural College at Guelp. This stock was carried for many years at the experiment station at St. Paul, Minn., under Minnesota Nos. 32 and 105. It consisted of an indefinite number of biological strains and numerous selections were made at various times. Minnesota No. 184 produced higher yields than the other selections and has been used as the standard variety since 1918. It has been tested in plats since 1915 and in the three years, 1920 to 1922 inclusive, gave an average yield 3 bushels per acre greater than the parent variety.

With the application for registration Hayes reported both rod-row and plat yields at University Farm and the substations for a five-year period. These are omitted from this statement due to the need for brevity, but yields were reported by the Minnesota Experiment Station and will be found in U. S. D. A. Bulletin No. 1334 under C. I. Number 2330. The same is true of the two following varieties.

Minnesota No. 184 in appearance is a typical Manchuria. It is 6-rowed, white, hulled and has a bluish cast to the aleurone layer. The basal bristle is short-haired and the average density is about 3.4 or 3.5 mm.

MINSTURDI—Minnesota No. 439, Reg. No. 1556

Submitted by H. K. Hayes. This variety is a selection from a hybrid made in the cooperative barley studies of the Minnesota Experiment Station and the U. S. Department of Agriculture. A cross was made in 1909 between South African and Manchuria. The South African was a club variety similar to the Winter Club found occasionally in the West. It was very late in heading in Minnesota and probably had some winter habit. Pollen was taken from a plat of unselected Manchuria. The last selection was made in 1914. The variety has been grown and yields reported from both the central station and the substations. The strength of straw of this variety has been found of advantage particularly on rich soil.

The spike of Minsturdi is 6-rowed and slightly more dense than Manchuria, averaging around 2.8 mm. The aleurone, as well as the hull, is white and the rachilla short-haired.

SVANSOTA—Minnesota No. 440, Reg. No. 1907

Submitted by H. K. Hayes. This variety, as well as Minsturdi, originated in cooperative breeding experiments. In 1909, H. V. Harlan attempted to test a then current theory of regeneration by crossing a newly imported Svanhals on one grown in Minnesota for a number of years. The Minnesota sample proved to be not true to name, being possibly a field hybrid. A test of regeneration was thus impossible and the experimenter has forgotten whether he couldn't change his mind or whether he did not want to. In any case the cross was made and in later years Svansota was selected from it. Svansota is a 2-rowed variety similar in appearance to Svanhals. It has proved to be superior to French Chevalier and has been increased for distribution in northeastern Minneosta where it has been shown to be well adapted.

AGRONOMIC AFFAIRS

ANNUAL MEETING OF THE AMERICAN SOCIETY OF AGRONOMY

The next annual meeting of the Society will be held at the New Willard Hotel in Washington, D. C., on Thursday and Friday, November 18 and 19, 1926. Detailed announcements of the program and other arrangements for the meeting will be mailed to members early in October.

MEETING OF THE AMERICAN SOIL SURVEY ASSOCIATION

This Association will hold its 1926 meeting in Washington, D. C., on Tuesday and Wednesday, November 16 and 17.

PRELIMINARY ANNOUNCEMENT OF THE FIRST INTERNATIONAL CONGRESS OF SOIL SCIENCE

In accordance with the decision of the Fourth International Conference of Soil Science that met in Rome, in May, 1924, the First Congress of the International Association of Soil Science, then organized, will convene on June 13, 1927, in Washington, D. C. The Congress will be followed by a field excursion to visit the various important soil belts in the country. Opportunity will also be given to the delegates to acquaint themselves with various agricultural industries, some of the leading agricultural experiment stations, and in general with the agricultural resources of the United States.

The Association is made up of the following six International Commissions:

I *Commission on Soil Physics*

Chairman—Dr. V. Novak, Chef de l'Institut Pedologique, Kvetna 19, Brno, Czechoslovaka

II *Commission on Soil Chemistry*

Chairman—Prof. Dr. A. deSigmond, Technische Hochschule, Szent-Gallertter, 4, Budapest, Hungary

III *Commission on Soil Bacteriology*

Chairman—Prof. Dr. Julius Stocklasa, Professor an der Böhmischen, Technischen Hochschule und Direktor, der Staatlichen Versuchsstation, Vinohrady, Prague, Czechoslovakia

IV *Commission on Soil Fertility*

Chairman—Prof. Dr. E. A. Mitscherlich, Pflanzenbau-Institute der Universitat Tragheimerkirchenstrasse 83, Königsberg, Germany

V *Commission on Nomenclature, Classification and Cartography*

Chairman—Prof. C. F. Marbut, Bureau of Soils, Department of Agriculture, Washington, D. C.

Sub-Commission on the Preparation of the Cartography of Europe

Prof. Dr. H. Stremme, Mineralogisch-Geologisch Institut der Technischen Hochschule, Neptunstrasse 14, Danzig, Germany

VI *Commission on the Application of Soil Science to Land Cultivation*
Chairman—Dr. J. Girsberger, Kultur-Ingenieur des Kantons Zurich, Kaspar Escherhaus, Zurich, Switzerland

The American representatives of these Commissions are:

I Dr. C. Davis, Bureau of Soils, Washington, D. C.
II Dr. M. M. McCool, East Lansing, Michigan
III Dr. S. A. Waksman, New Brunswick, N. J.
IV Prof. D. R. Hoagland, Berkeley, California
V Dr. C. F. Marbut, Bureau of Soils, Washington, D. C.
VI Dr. S. H. McCrory, Bureau of Agricultural Engineering, Washington, D. C.

Each Commission is now working on the preparation of its own program. Some of the sessions will be devoted to the Congress as a whole or to combined meetings of more than one Commission, while a number of sessions (5 to 8) will be devoted to the special sessions of each Commission.

The program of each Commission will consist of papers presented by invitation by outstanding investigators in the respective fields, and of papers presented by various workers in the different branches of soil science, by members or non-members of the Association. Titles of the papers to be presented and brief abstracts in English, French and German should be sent on or before December 1st., either to the respective Chairman, or to the American representative of the Commission, where the paper is to be presented, or to the President of the Association, who will have the paper forwarded to the Chairman of the corresponding Commission.

This Congress will bring together in this country, for the first time in its history, all those that are interested in the different problems of soil classification, soil analysis, fertilization and treatment, as well as the relation of the soil to plant growth. Extensive exhibits of various soil types (monolithic columns, in respective horizons) from Europe and America, apparatus used in soil analyses, of the soil microflora and microfauna, etc. will be held during the Congress.

Dr. J. G. LIPMAN,
President International Society of
Soil Science, New Brunswick, N. J.
Dr. D. J. Hissink,
Secretary, Groningen, Holland

NEWS ITEMS

The following men became members of the staff of the agronomy department at the Illinois Agricultural Experiment Station on September 1 of this year: C. J. Bradley, Assistant in Soil Physics; C. E. Rosenquist, Assistant in Plant Breeding; and Collins Veatch, Assistant in Plant Breeding.

C. C. Ruth, Associate Professor of Farm Crops, and E. R. Jackman, Extension Specialist in Farm Crops, at the Oregon Agricultural College at Corvallis, have resigned effective August 15.

Roscoe E. Bell has been appointed a teaching fellow in soils, and Karil Daniloff a research fellow in crops, at Washington State College for the coming academic year. A. Floyd Heck, who has been teaching soils and crops, will be absent on leave for graduate study at the University of Wisconsin for the year.

At Purdue University, M. L. Fisher, who has been Head of the Department of Agronomy and Assistant Dean of the School of Agriculture, was made Dean of Men for the University on July 1. He will retain his title of Professor of Agronomy and do some teaching as his new duties may permit. The teaching, research, and extension work in soils and crops have been consolidated into a single department under the supervision of A. T. Wiancko as Head of the Department of Agronomy. G. H. Cutler, formerly of the University of Alberta, has been appointed Professor of Agronomy and Assistant Head of the Department and will have charge of the work in plant breeding.

Lilburn Allen, formerly Assistant in Soil Survey Analysis in the Agronomy Department at the Illinois Agricultural Experiment Station, has accepted a fellowship given by the National Lime Association. He will work the coming year at the Ohio State University on the problem of "Fineness of Limestone."

The sixth annual school in cotton classing and stapling conducted by the Agronomy and Agricultural Economics Departments of the Oklahoma A. & M. College, at Stillwater, was held during the four weeks of July 5 to 31. One hundred and twelve farmers, ginners, cotton buyers, and students enrolled for the course. Of these nine were college students taking the course for college credit.

L. B. Broughton, after receiving his Ph.D. degree from the Department of Soils at Ohio State University in August, has resumed his work as Professor of Chemistry at the University of Maryland.

T. E. Richmond, formerly of the University of Illinois, has been appointed an instructor in soils at Ohio State University and will also work for his Ph.D. degree at that institution.

H. W. Blaisdell has been appointed a research fellow in soils, and Oliver Lee a teaching fellow in farm crops, at the State College at Pullman, Washington.

C. J. Willard has been promoted from Assistant Professor to Professor in the Department of Farm Crops at Ohio State University.

D. N. Lutz, who has been engaged for the past five years in agricultural mission work in Korea, is spending the present year on furlough doing graduate work in farm crops at Ohio State University.

George D. Scarseth has resigned his position as Assistant in Soils at the Connecticut Agricultural Experiment Station, in order to become the soils expert for the United Fruit Co., with headquarters at Tela, Honduras. H. G. M. Jacobsen, formerly a member of the Department of Agronomy of the University of Arkansas, has been appointed to fill the vacancy at the Connecticut Station.

H. H. Bennett, of the Soil Survey Division of the United States Bureau of Soils, has recently returned to Washington from Cuba, after making a reconnaissance survey of the southern part of the island for the U. S. Department of Agriculture in cooperation with the Cuban Sugar Club.

J. H. Stallings, formerly of the Department of Agronomy of the Texas A. & M. College, has been appointed Head of the Department of Agronomy of the J. C. Penny-Gwinn Institute of Applied Agriculture at Green Cove Springs, Florida.

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ACTIVATED SLUDGE: ITS PRODUCTION, COMPOSITION, AND VALUE AS A FERTILIZER[1]

O. J. NOER[2]

Agriculturists and conservationists have repeatedly called attention to the enormous losses of nitrogen, phosphoric acid, and potash occasioned by present methods of sewage disposal. Bruttini (7)[3] estimates that the annual excrement of the world's population contains approximately nine million tons of nitrogen and close to a million tons each of phosphoric acid and potash, most of which is lost to agriculture. On this basis the annual loss in the United States in human excrement approximates half a million tons of nitrogen, valued at $180,000,000, and more than one hundred thousand tons each of phosphoric acid, valued at $12,000,000, and potash, valued at $10,000,000.

Unfortunately, most of the nitrogen in sewage is in soluble form, and the large amounts of water used to carry the sewage make recovery both difficult and expensive. Attempts to irrigate agricultural lands with sewage have not been generally successful, and trials with sludges produced by the Imhoff, septic tank, and precipitation processes have never yielded results sufficiently promising to warrant the large expenditures necessary to produce a dry fertilizer. The use of these sludges has been limited and confined to areas in the immediate vicinity of the disposal plant. With the discovery and perfection of the activated sludge process of sewage disposal in recent years, interest in fertilizer recovery has again been aroused, because this process produces a sludge of higher nitrogen content. The material produced by this process is commonly called activated sludge.

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[1] Part I of a thesis submitted at the University of Wisconsin in partial fulfillment of the requirements for the degree of doctor of philosophy. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station. This work was conducted under a fellowship grant from the Milwaukee Sewerage Commission of Milwaukee, Wisconsin. Received for publication June 4, 1926.

[2] Fellow, Department of Soils, University of Wisconsin. The writer wishes to express his appreciation for helpful suggestions and criticisms tendered by Prof. E. Truog, under whose general direction the work was done.

[3] Reference by number is to "Literature Cited," p. 962.

Dried activated sludge, a dark brown organic material free of disease-producing organisms, is valuable chiefly for the nitrogen it contains. Dried samples, procured from the cities indicated, gave on analysis the following percentages of fertilizer constituents:

	Milwaukee, Wisc.	Houston, Texas %	Maywood, Ill. %	Pasadena, Calif. %
Total nitrogen	6.37	4.84	4.72	6.41
Water soluble nitrogen	0.49	0.84	0.72	2.61
Water insoluble nitrogen	5.88	4.00	4.00	3.80
Total phosphoric acid	2.99	2.33	4.20	3.94

Occasional samples have given more than 7% total nitrogen. The activity of the water insoluble nitrogen runs as high as 65, determined by the alkaline permanganate method, and 90 as determined by the neutral permanganate method. About 75% of the phosphoric acid is soluble in neutral ammonium citrate solution. The potash content is generally less than 0.5%, although Brenchley and Richards (4) report 1.12% in Withington activated sludge.

The amount of phosphoric acid found in the different sludges shows considerable variation, and some sludges carry a sufficient amount to deserve attention in connection with measures for the conservation of phosphates as a national program. It is probable that improvements in the method will follow which will make possible an increase in the phosphoric acid content of the sludge produced.

THE ACTIVATED SLUDGE PROCESS

In the activated sludge process, after it is once in complete operation, the raw sewage is first thoroughly inoculated with the organisms concerned in the process by mixing with it a considerable amount of previously produced, fresh, undewatered activated sludge. This mixture is then run into large tanks, at the bottom of which a large amount of air is introduced in the form of fine bubbles to produce active aeration and agitation. This aeration promotes vigorous biological and chemical activity, which causes a flocculation of the suspended colloidal material, that is, a gathering together of the finely divided particles into larger particles. After four to six hours of aeration, the particles become sufficiently large to settle out rapidly and the aerated sewage is then run into large settling tanks where the suspended matter quickly settles out, and the clear effluent or purified water is allowed to run into streams and lakes without danger of pollution. The material which settles out is the so-called activated sludge. One portion of this sludge is either put through a dewatering and drying process to make it fit for fertilizer use or else is otherwise disposed of. The other portion, which has not been dewatered, is mixed with the raw sewage for inoculation as previously explained. Due to intense aeration and thorough inoculation, a purification is effected in a few hours in the aeration tanks which takes days when sewage is simply run into streams.

The activated sludge process is quite different from the Imhoff and septic tank processes which are essentially anaerobic, that is, are carried on without the introduction of air. This results in a digestion and destruction of the organic matter, with a loss of nitrogen, and the production of a sludge of much lower fertilizing value than is produced in the activated sludge process. According to Richards and Sawyer (10), the Imhoff and septic tank processes recover only about 4% of the total nitrogen in the sewage, while the activated sludge process recovers about 20%.

THE MILWAUKEE ACTIVATED SLUDGE PROJECT

The Milwaukee Sewerage Commission, after a thorough investigation, adopted the activated sludge process as best adapted to the city's needs. The new plant, now practically completed, will produce approximately 35,000 tons of dry fertilizer per annum, and represents the first attempt at large scale production of fertilizer from sewage.

Although small amounts of activated sludge have been produced at various places, and its value as a fertilizer has been investigated to some extent, the Milwaukee Sewerage Commission desired more complete information regarding its fertilizer value and for this purpose established a fellowship at the University of Wisconsin. The more important results obtained in the investigation under this fellowship are next presented.

AVAILABILITY OF THE NITROGEN IN ACTIVATED SLUDGE

Activated sludge was compared with a number of organic nitrogen carriers in pot tests in the greenhouse. A nitrogen-free sand was used in the pots, and the various nitrogen carriers were added to supply equivalent amounts of nitrogen, but in insufficient quantity to mature the crop completely. Ample amounts of other essential elements were supplied in soluble form, together with soil infusions to insure suitable bacterial inoculation. At the end of about two months, when growth ceased, because of exhaustion of available nitrogen, the plants, including roots, were removed from the pots, dried, weighed, and analyzed to determine the amount of nitrogen made available and taken up by the plants in each case.

In one of these experiments activated sludge was compared with low and high grade tankages, dried blood, hoof meal, digested leather, cottonseed meal, and garbage tankage. The percentages of added nitrogen made available and taken up by oats during 65 days are summarized in Table 1.

TABLE 1.—*Percentage of nitrogen in activated sludge and other nitrogen carriers made available and taken up by oats during 65 days growth in quartz sand cultures.*

Source of nitrogen	Total nitrogen in fertilizer material	Amount of added nitrogen taken up by crop
	%	%
Activated sludge	4.95	36.1
Fertilizer tankage (low grade)	4.64	37.9
Fertilizer tankage (high grade)	8.26	32.3
Feeding tankage	9.70	48.9
Dried blood	10.71	46.2
Hoof meal	13.02	52.0
Digested leather	8.24	23.1
Cottonseed meal (1)	6.51	44.4
Cottonseed meal (2)	7.30	39.2
Garbage tankage (1)	1.72	5.8
Garbage tankage (2)	2.62	0.4

These results, and others from similar experiments, show that activated sludge compares favorably with fertilizer tankage and cottonseed meal as a source of nitrogen, and is superior to digested leather.

Lipman and Burgess (9) compared organic nitrogen carriers by measuring nitrate accumulation in a soil and concluded that activated sludge resembles the high grade organic nitrogen carriers. Baer (2), in similar tests, obtained as rapid nitrate production from activated sludge as from cottonseed meal, and in this respect these two were only slightly inferior to dried blood. Brenchley and Richards (4), however, obtained only half as much nitrate from activated sludge as from dried blood. In pot cultures with barley, Brenchley and Richards (4) secured higher yields with activated sludge than with nitrate of soda, but a second crop of mustard, grown to determine the residual effect, gave much larger increases where nitrate of soda had been applied. Evidently, the fertilizer applications were very heavy. Bartow and Hatfield (3) and later Hatfield (8) obtained excellent results with activated sludge in pot cultures.

FIELD EXPERIMENTS WITH ACTIVATED SLUDGE

A few field trials have been conducted by other investigators. Bartow and Hatfield (3) increased the yield of lettuce 50%, and of radishes 300%, above the check plats with an application of 1 ton per acre of activated sludge. Richards and Sawyer (10), in field trials with grass, barley, and potatoes, compared activated sludge with sulfate of ammonia and barnyard manure, and found that activated sludge compared favorably with the other nitrogen carriers. Arden (1) obtained as good results with activated sludge as with ammonium sulfate on spring wheat. Brown (5, 6) compared activated sludge with a number of other nitrogen carriers, using a variety of crops, and found activated sludge to be a good source of nitrogen.

The field experiments were designed to test the value of activated sludge as a nitrogen carrier under field conditions. Various mixtures were made, some in which all the nitrogen was supplied from activated sludge, sulfate of ammonia, or tankage, and others in which a portion of the nitrogen was supplied from activated sludge or tankage and the balance from sulfate of ammonia and nitrate of soda. In some cases commercial mixtures of corresponding analyses were also used.

TABLE 2.—*Yields of cabbage secured with fertilizers containing nitrogen from activated sludge and other sources.*

Fertilizer analysis	Source of nitrogen	Yield in tons per acre
0–10–6	No nitrogen	11.16
4–10–6	Activated sludge	13.45
4–10–6	Sulfate of ammonia	12.36
No fertilizer		7.56
4–10–6	Tankage	12.82
4–10–6	Activated sludge, ⅔ Sulfate of ammonia, ⅓	12.80
4–10–6	Activated sludge, ⅔ Nitrate of soda, ⅓	12.71
4–10–6	Activated sludge, ½ Sulfate of ammonia, ¼ Nitrate of soda, ¼	13.85
No fertilizer		8.19
4–10–6	Activated sludge, ¼ Sulfate of ammonia, ½ Nitrate of soda, ¼	13.60
4–10–6	Tankage, ¼ Sulfate of ammonia, ½ Nitrate of soda, ¼	13.85
2–10–6	Sulfate of ammonia. ½ Nitrate of soda, ¼	12.40

An experiment with cabbage was conducted on a Carrington silt loam at Somers, Wis. The field had been in hay for four years and received a light top-dressing of manure in the spring. Broadcast applications of fertilizer were made at the rate of 1,200 pounds per acre, prior to setting the plants. The treatments and yields are summarized in Table 2.

All the 4-10–6 mixtures, with one exception, produced larger yields than the 0–10-6 or 2 10–6 mixtures, and activated sludge proved fully as effective as any of the other sources of nitrogen.

In an experiment with tomatoes on a sandy soil fertilizers were applied with an attachment on the planter at the rate of 500 pounds per acre. The 4 8-6 commercial mixture checked the early growth of the plants. This did not occur with the sludge mixtures used. Tomatoes were picked up to September 5, and the yields are summarized in Table 3.

TABLE 3.—*Yields of tomatoes obtained with fertilizers containing nitrogen from activated sludge and other sources.*

Fertilizer analysis	Source of nitrogen	Yield per plat in pounds
4–8–6	Commercial mixture	864
0–8–6	No nitrogen	373
No fertilizer		397
4–8–6	Activated sludge	839
4–8–6	Activated sludge, ⅔ Nirate of soda, ⅓	1,155

The use of nitrogen in addition to phosphate and potash materially increased the yield. Activated sludge proved to be a good source of nitrogen. The largest increase was obtained where a mixture of nitrate of soda and activated sludge supplied the nitrogen.

TABLE 4.—*Yield of corn and fodder obtained with fertilizers containing nitrogen from activated sludge and other sources.*

Fertilizer treatment	Source of nitrogen	Yield per acre Fodder in pounds	Yield per acre Corn in bushels	Increase in corn per acre in bushels
No fertilizer		3,530	31.5	——
0–12–0	No nitrogen	2,985	31.4	+0.4
0–12–2	No nitrogen	2,910	31.9	+1.3
No fertilizer		2,716	30.2	——
2–12–0	Commercial mixture	2,925	34.9	+5.1
7–3½–½	Activated sludge alone	2,850	30.2	+1.0
No fertilizer		2,671	29.0	——
6–2–2	Activated sludge	2,694	30.8	+1.4
2–12–2	Activated sludge	2,910	38.4	+8.4
No fertilizer		2,656	30.8	——
2–12–2	Commercial mixture	2,836	38.2	+7.1
2–12–2	Sludge, ½ Sulfate of ammonia, ½	2,880	35.3	+3.7
No fertilizer		2,895	32.1	——

In an experiment with corn fertilizers were applied in the hill at the rate of 150 pounds per acre with an attachment on the planter. This experiment was located on a light sandy loam soil which received no other fertilizer treatment. Yields are summarized in Table 4.

Activated sludge alone or mixed with potash did not increase the yield appreciably, but when used in conjunction with acid phosphate it proved to be as good a source of nitrogen as any other used.

In a number of trials with potatoes fertilizers were applied in the row and to the side of the seed at rates varying from 500 to 1,000 pounds per acre. The increased yields in bushels per acre are reported in Table 5, together with the average yield of the four check plats. In calculating the increased yields any variations between successive check plats were assumed to be progressive.

In general, activated sludge was less effective than sulfate of ammonia or tankage as the sole source of nitrogen. The largest increases, however, were generally obtained with mixtures containing both organic and inorganic nitrogen, and under these conditions activated sludge proved fully as effective as tankage.

USE OF ACTIVATED SLUDGE ON GOLF COURSES AND LAWNS

In numerous trials on golf courses and lawns activated sludge has given good results. It is an excellent source of nitrogen for use on golf course greens when applied mixed with the usual soil and sand top-dressing mixture. Activated sludge also gives good results on lawns and golf course fairways when used as the source of nitrogen in the fertilizer mixture. Very striking results have been obtained on new bluegrass seedings with a combination of activated sludge and acid phosphate. Pasture fertilization is beginning to receive serious attention and it is possible that activated sludge may be used for the fertilization of bluegrass and other nonleguminous pastures.

ACTIVATED SLUDGE AS A FERTILIZER CONDITIONER

Activated sludge possesses another property of particular interest to the fertilizer manufacturer. Its organic colloidal nature and porous structure improves the mechanical condition of fertilizer mixtures. Samples of the various mixtures used during the past field season have now been in storage for almost a year under conditions similar to those obtaining in the average fertilizer warehouse. Even the mixtures in which only one-fourth to one-half the nitrogen is supplied from activated sludge are still in good mechanical condition.

TABLE 5.—*Increases in yields of potatoes secured with fertilizers containing activated sludge and other materials as sources of nitrogen.*

Soil type and location of field	Average yield of check plats in bushels per acre[a]	Increases over no fertilization, in bushels per acre, with fertilizers indicated									
		No nitrogen 0–10–6	Activated sludge 4–10–6	Sulfate of ammonia 4–10–6	Tankage 4–10–6	Activated sludge ⅔, sulfate of ammonia ⅓, 4–10–6	Activated sludge ⅔, nitrate of soda ⅓, 4–10–6	Activated sludge ½, sulfate of ammonia ¼, nitrate of soda ¼, 4–10–6	Activated sludge ¼, sulfate of ammonia ½, nitrate of soda ¼, 4–10–6	Tankage ¼, sulfate of ammonia ½, nitrate of soda ¼, 4–10–6	Tankage ¼, sulfate of ammonia ½, nitrate of soda ¼, 2–10–6
Antigo silt loam, Antigo, Wis.	264.0	57.1	97.4	71.1	77.2	87.8	85.4	71.3	92.2	79.1	68.8
Plainfield sandy loam, Starks, Wis.	194.1	51.1	59.9	76.0	83.5	76.4	75.2	69.2	80.4	74.6	59.7
Plainfield sandy loam, Harshaw, Wis.	245.8	65.7	42.8	83.6	137.4	113.5	121.5	123.5	120.5	122.5	56.4
Vilas sandy loam, Laona, Wis.	290.0	6.9	7.6	45.0	2.3	32.0	41.0	38.0	60.0	55.0	29.0
Plainfield sandy loam, Portage, Wis.	113.5	—1.9	25.3	7.0	44.1	19.7	6.8	30.2	40.5	46.7	30.3
Average increase		37.8	46.6	56.5	68.9	65.9	66.0	66.4	78.7	75.6	48.8

[a] Average of four plats except at Harshaw, Wis., where there were only two.

THE NEED FOR ORGANIC NITROGEN CARRIERS

Organic nitrogen carriers exert a favorable effect on the mechanical condition of the fertilizer mixture, and their inclusion in high analysis mixtures reduces the danger of injury to the young plant when the fertilizer is applied in the row. Furthermore, their use results in a minimum loss by leaching, due to the fact that the nitrogen becomes available as required by the growing plant, and in this respect they will probably always have a certain advantage over inorganic forms and will probably always be used to supply a portion of the nitrogen in mixed goods. The inorganic forms of nitrogen are, in the main, more readily available, but are more easily lost by leaching and do not help as much to improve conditions for desirable bacterial activity as the organic forms. Undoubtedly, a mixture of inorganic and organic nitrogen which combines the desirable qualities of both forms will always prove to be the best method of supplying the nitrogen in mixed fertilizers for general use. Some of the organic nitrogen carriers previously used by the fertilizer manufacturer are now being diverted into stock feeds, while the supply of others has become partly exhausted or has not kept pace with the growing demand and there is thus a growing shortage of organic fertilizer materials. Activated sludge, because of its good qualities as an organic nitrogen carrier and fertilizer conditioner, is well adapted to fill this shortage. Based on present day fertilizer values, high grade activated sludge is worth about $25 per ton.

SUMMARY

Water-carriage methods of sewage disposal result in enormous losses of nitrogen, phosphoric acid, and potash. The new activated sludge process of sewage purification offers possibilities of fertilizer recovery from sewage. It produces a sludge of high nitrogen and phosphoric acid content, and the method deserves serious consideration as a conservation measure. Future improvements in the method may considerably increase the amounts of nitrogen and phosphoric acid recovered.

Dried activated sludge produced with present day methods contains from 4.75 to 6.5% nitrogen and from 2.3 to 4.0% phosphoric acid.

In pot tests in the greenhouse with oats activated sludge as a source of nitrogen proved about equal to cottonseed meal and fertilizer tankage and considerably better than digested leather.

Field trials with cabbage, tomatoes, corn, and potatoes indicated that activated sludge is a satisfactory source of organic nitrogen for use in mixed fertilizers. Activated sludge exerts a favorable influence upon the mechanical condition of mixed fertilizers. It helps to prevent setting of the mixtures, makes uniform distribution easier, and reduces the danger of injury to the young sprout.

In numerous trials on golf courses and lawns the use of activated sludge as the source of nitrogen in the fertilizer mixture has given excellent results.

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REMOVAL OF PLANT FOOD IN THINNING CORN[1]

JEHIEL DAVIDSON[2]

The avidity for mineral plant food exhibited by young seedlings noted in a previous investigation[3] suggested the advisability of exercising caution in the practice of thinning in order that too much available plant food should not be removed from the immediate vicinity in which the remaining plants are to grow. It was the object of the present preliminary investigation to obtain some data as to the quantities of nitrogen, potassium, and phosphorus removed in thinning corn by analyzing the pulled-out corn seedlings.

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[1] Contribution from the Crop Chemistry Laboratory, Bureau of Chemistry, U. S. Department of Agriculture, Washington, D. C. Received for publication June 17, 1926.

[2] Associate Chemist.

[3] DAVIDSON, JEHIEL. Effect of hydrogen-ion concentration on the absorption of phosphorus and potassium by wheat seedlings. Unpublished manuscript.

The material for analysis was obtained from the various plats used at the Arlington Farm in studying the relative effects of ammonium sulfate and sodium nitrate on the yield and composition of corn. The experiment was run in triplicate. Four kernels of Boone County white corn (C. I. No. 119) were planted in each hill. Eighteen days after planting the hills were thinned out to three and a week later to two plants. Less than four plants came up in some hills, and the plats being small (4 x 5 hills), insufficient material for analysis was obtained in the first thinning. The seedlings from identical triplicates were therefore put together and used for analysis collectively. The seedlings were pulled carefully to avoid root pruning as much as possible. The roots were thoroughly cleaned from adhering soil particles. Four seedlings were used for the nitrogen determinations, which were made in triplicate, and the ash of three seedlings was used for the determination of both phosphorus and potassium, made in duplicate. The same numbers of kernels were taken for the analysis of the stock seed used for planting in which the nitrogen was determined in five replications and the phosphorus and potassium in triplicate. The nitrogen determinations in the seedlings were made by the modified Gunning method, but, owing to the high moisture content of the fresh material, part of the nitrates may have been lost.

The average results, calculated to one seed or seedling, are given in Table 1.

TABLE 1.—*Nitrogen, potassium, and phosphorus removed from the soil by the pulled-out corn seedlings in the first thinning.*

Material	Treatment	In one kernel or seedling			Absorbed from soil by one seedling		
		N	K_2O	P_2O_5	N	K_2O	P_2O_5
		mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Seed		6.95	1.56	3.80	—	—	—
Seedlings	Controls	11.47	12.40	1.87	4.52	10.84	—1.93
Seedlings	Sodium nitrate	14.35	17.20	2.40	7.40	15.64	—1.40
Seedlings	Ammonium sulfate	12.50	13.40	3.03	5.55	11.84	—0.77

It is noteworthy that while the seedlings absorbed relatively large quantities of potassium and nitrogen, they contained less phosphorus than the original seed. Corn seedlings evidently could not be used for the estimation of available phosphorus in soils by the Neubauer method.[4] However, this apparent loss of phosphorus from the corn seedlings does not necessarily have any bearing on the much-debated question of the migration of food elements from the plant to the soil,[5] as the losses shown here might have been due to slight root pruning and to seed debris left behind when the seedlings were pulled out.

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[4] NEUBAUER, H., and SCHNEIDER, W. Die Nährstoffaufnahme der Keimpflanzen und ihre Anwendung auf die Bestimmung des Nährstoffgehaltes der Böden. *In* Zeit. für Pflanzen Ernahrung und Dungung, 2:a, 329–362. 1923.

The differences between the variously treated plats were entirely consistent. Not only was the nitrogen content of the seedlings from the treated plats higher than that of the controls, but so were the potassium and phosphorus contents, owing probably to more vigorous growth. The nitrogen content of the seedlings from the sodium nitrate plats was higher than that of the seedlings treated with ammonium sulfate. The potassium content was higher in the seedlings from the sodium nitrate plats and the phosphorus content was higher in those from the ammonium sulfate plats than in the others. This was probably due to differences in reaction caused by the two salts in the immediate vicinity of the growing plants. It has been found[6] that potassium is physiologically more available to young seedlings in a less acid medium and phosphorus in a more acid medium.

The second thinning furnished more material for analysis than the first owing to the fact that very few hills had less than three seedlings and the replications were therefore from individual plats having the same treatment. Nitrates were determined by the Devarda method, the organic nitrogen, in the residues from the Devarda determinations, by the ordinary Gunning method, and ammonia by distillation with magnesium oxide in separate samples. The Devarda

TABLE 2.—*Nitrogen, potassium, and phosphorus removed from the soil by the pulled-out corn seedlings in the second thinning.*

Material	Treatment	In one kernel or seedling						Absorbed from soil by one seedling		
		Nitrogen								
		Nitrate	Ammonia	Organic	Total	K_2O	P_2O_5	N	K_2O	P_2O_5
		mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Seed	———	——	——	——	6.95	1.56	3.80	——	——	——
Seedlings	Control	5.34	1.40	21.19	27.93	38.87	3.69	20.98	37.31	—0.11
Seedlings	Sodium nitrate	5.01	1.61	23.01	29.63	45.54	4.32	22.68	43.98	+0.53
Seedlings	Ammonium sulfate	4.73	1.75	17.23	23.71	44.02	4.40	16.76	42.46	+0.60

[5] WILFARTH, H., RÖMER, H., and WIMMER, G. Über die Nährstoffaufnahme der Pflanzen in verschiedenen Zeiten ihres Wachstums. *In* Land. Versuch. Sta., 63:1–70. 1906.

[6] See footnote 3.

values were corrected by subtracting the ammonia values from them. Otherwise the procedure was the same as for the first thinning.

The average results calculated to one seedling are given in Table 2. A comparison of the amounts of nitrogen and potassium removed by the seedlings at the two consecutive thinnings shows that absorption in the week which elapsed between them was about twice as active as during the period between the planting and the first thinning. The absorption of phosphorus was still low. The phosphorus content of the controls was less than that of the original seed; that of the seedlings from the treated plats was slightly higher than that of the seed. The effect of fertilizer treatment, particularly with reference to nitrogen, was less pronounced than at the first thinning. The seedlings from the sodium nitrate plats still contained a little more nitrogen than the controls, but those from the ammonium sulfate plats fell below the controls in nitrogen content. It is possible that the ammonium sulfate interfered with nitrification, having caused increased acidity in the immediate vicinity of the hills. This assumption seems to be supported by the fact that the nitrate content of the seedlings from the ammonium sulfate plats was lower than that of the seedlings from the other plats. The differences in the ammonia content seem to be consistent. The differences in the absorption of potassium and phosphorus, while being on the whole smaller than in the case of the first thinning, nevertheless followed the same course.

TABLE 3.—*Total nitrogen, potassium, and phosphorus removed from one hill in thinning.*

Treatment	N *mg.*	K_2O *mg.*	P_2O_5 *mg.*
Controls	25.50	48.15	—2.04
Sodium nitrate	30.08	59.62	—0.87
Ammonium sulfate	22.31	54.30	—0.17

Table 3 gives the total quantity of nitrogen, potassium, and phosphorus, respectively, removed from each corn hill in the two thinnings. The results show appreciable losses in potassium and nitrogen from the soil, accompanied by slight gains in phosphorus. These losses will naturally differ widely, depending upon environmental conditions, number of seedlings removed, and time of thinning. Although not resulting in any ultimate loss to the soil, as the pulled-out corn seedlings are generally left in the field, the plant food removed in this way is nevertheless lost for the immediate use of the young plants remaining in the hills. In terms of plant food per acre, the losses shown here are insignificant, but in terms of plant food available for absorption by the young seedlings until the time of thinning, each plant removed about 25% of that food in the first thinning and about 33.3% in the second thinning. No experimental evidence is available as to the actual effect on the remaining plants of this removal of plant food during thinning. Moreover, thinning is unavoidable in the cultivation of many crops and under normal conditions any losses resulting from it are just as inevitable as those from drainage, run-off, etc. However, more caution in planting and thinning may reduce the possible ill effects of this practice. For instance, more reliance should be placed upon the viability of the seed and protection from birds than on the number of seeds to insure the required number of plants. Further, thinning should be attended to without any delay because, as shown here, the quantity of removed plant food increases rapidly with the advancement in age of the pulled-out corn seedlings.

The problem seems to deserve further study.

SUMMARY

Corn seedlings removed during two successive thinnings were analyzed to determine their content of nitrogen, potassium, and phosphorus. The pulled-out corn seedlings removed considerable quantities of nitrogen and potassium from the hills, but left behind small quantities of the phosphorus originally contained in the seed.

During the week between the first and second thinning about twice as much potassium and nitrogen was absorbed by the corn seedlings as during the period between planting and the first thinning.

Nitrates and ammonium salts were present in the young corn seedlings in appreciable quantities

The application of sodium nitrate and ammonium sulfate increased the absorption of nitrogen, potassium, and phosphorus by the seedlings consistently during the period between planting and the time of the first thinning, but this effect became less pronounced a week later at the time of the second thinning.

The importance of prompt thinning and of avoiding overplanting is emphasized.

NATURAL CROSSING IN SOYBEANS[1]

R. J. GARBER and T. E. ODLAND[2]

The soybean plant is naturally self-pollinated, although cross pollination occurs. Several plant breeders have determined the extent of natural crossing under certain conditions and the results have shown that very little crossing takes place.

In an experiment carried on at the Wisconsin Experiment Station, Woodworth[3] found one hybrid pod in 625, or 0.16%. In this investigation two varieties were interplanted in such a way as to provide the greatest opportunity for natural crossing.

In the soybean varietal experiments carried on at the West Virginia Experiment Station, each variety is grown in four-row plats with the rows 30 inches apart. The investigation here reported had for its object the determination of the extent of natural crossing between different varieties in adjacent rows.

METHODS

The percentage of natural crossing may be determined on the basis of the relative number of pods which contain hybrid seed as was done by Woodworth, or on the basis of relative number of hybrid seed. The latter method was used in this investigation. From a practical standpoint, the plant breeder is interested primarily in the extent of contamination of a certain variety, and natural crossing between different flowers of the same plant or between flowers of different plants of the same pure line variety is not a source of contamination.

In 1922 ripened pods were selected at random from rows of Manchu, Haberlandt, Ohio 9016, and Elton which were grown adjacent to rows of Wilson and Hamilton (Ohio 9035). The four varieties first named have yellow seed-coats, whereas Wilson has a black and Hamilton a brown seed-coat. Before taking pods from any particular plant, it was examined to make sure that it was not a hybrid or a chance mixture. The pods so selected were dried and later the seed was hulled by hand. A random sample of seed of each variety with yellow seed-coats was planted the next season to determine the number of hybrids. At harvest each plant was examined and if a

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[2] Agronomist and Associate Agronomist, respectively.

[3] WOODWORTH, C. M. The extent of natural cross-pollination in soybeans. *In* Jour. Amer. Soc. Agron., 14:278–283. 1922.

particular plant showed any evidence of being a hybrid, seed from it was saved for a progeny test.

In a similar manner ripened pods from several varieties with yellow seed-coats were selected in 1923. In addition to the Hamilton and Wilson varieties, used in 1922, Black Eyebrow and Medium Green were grown in adjacent rows in 1923. The seed-coat colors of Hamilton and Wilson have been mentioned. The seed-coat of Black Eyebrow is black with a brown saddle. The cotyledons of all the varieties mentioned above, except Medium Green, and grown in 1922 or 1923 are yellow. The seed-coat and the cotyledons of the latter are green.

In addition to the varieties here considered there were grown in the same experimental field other varieties of soybeans. Inasmuch as natural cross-pollination in soybeans is likely owing to insect carriers, there is the possibility of hybridization between varieties grown at a considerable distance from one another. It would seem, however, that under the conditions of this experiment the greatest extent of natural crossing would take place between different varieties growing in adjacent rows.

The extent of crossing may also be influenced by the relative date of flowering of the several soybean varieties. Unfortunately, this note was not recorded. However, the date at which each variety was cut for forage was taken, and since each variety was harvested for forage at the same relative stage of maturity, this note may be used as an indication of the relative date of flowering.

In planning this investigation it was assumed that the F_1 plants which would result from crossing soybeans with yellow seed-coats with soybeans with green, black, or brown seed-coats could be distinguished among the plants with yellow seed-coats. For this reason random samples of the yellow-seeded varieties only were grown to determine the extent of natural crossing. Such an assumption may not be wholly justified with all of the above varieties. However, Woodworth[4] and Piper and Morse[5] have presented evidence that seems to warrant such a procedure.

PRESENTATION OF DATA

In 1922, as has been stated, ripened pods were collected from certain rows of four different varieties of soybeans which normally produce yellow seeds and which were grown adjacent to rows of soybeans that normally produce black or brown seeds. In 1923 something over 400 seeds of each variety were planted and a total of 1,512 plants (Table 1) were harvested and examined for evidence of hybridity. Of the several plants which were subjected to the progeny test, only one proved to be a hybrid. One is 0.07% of 1,512. If it is assumed that the reciprocal natural cross is as likely to occur as the one here described, the percentage of natural crossing which would lead to contamination of varieties grown under the given conditions would be 0.14.

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TABLE 1.—*The relative number of hybrid seeds owing to natural crossing in certain varieties of soybeans.*

The varieties grown in adjacent rows together with the date of harvest for hay of all the varieties grown in 1922 are also shown.

Variety in row sampled	Date harvested	Number of plants grown in 1923	Number of F_1 plants[a]	Adjacent row Variety	Adjacent row Date harvested
Manchu	Aug. 17	368	0	Wilson	Aug. 29
Haberlandt	Sept. 15	363	0	Wilson	Aug. 29
Ohio 9016	Aug. 26	379	0	Wilson	Aug. 29
Elton	Aug. 17	402	1	Hamilton Ohio 9035	Aug. 29
Total		1,512	1		

[a] Number of plants that proved to be hybrids as determined by the progeny test in 1924.

In Table 1 are also listed the dates of maturity for forage of the four varieties from which seed samples were collected as well as those of the varieties in adjacent rows. Haberlandt is by far the latest

TABLE 2.—*The relative number of hybrid seeds owing to natural crossing in certain varieties of soybeans.*

The varieties grown in adjacent rows together with the date of harvest for hay of all the varieties grown in 1923 are also shown.

Variety in row sampled	Date harvested	Number of plants grown in 1924	Number of F_1 plants[a]	Adjacent row Variety	Adjacent row Date harvested
Elton	Aug. 23	426	1	Hamilton (Ohio 9035)	Aug. 31
Ohio 9016	Aug. 31	503	0	Wilson	Aug. 31
Manchu	Aug. 20	448	0	Wilson	Aug. 31
Ohio 9100	Aug. 14	463	2	Wilson	Aug. 31
U. S. 36647	Aug. 20	456	2	Wilson	Aug. 31
Hollybrook	Sept. 4	504	0	Wilson	Aug. 31
U. S. 36901	Aug. 20	497	0	Black Eyebrow	Aug. 20
Ito San	Aug. 14	477	2	Medium Green	Aug. 27
Total		3,774	7		

[a] Number of plants that proved to be hybrids as determined by the progeny test in 1925.

maturing sort in this group. Other things being equal one would expect more natural crossing between varieties which flower at about the same time.

The data for determining the extent of natural crossing that took place in the varietal experiments in 1923 are presented in Table 2. In this year pods were collected from eight different varieties that normally produce yellow seeds. In 1924 something over 500 seeds of each variety were planted from which a total of 3,774 plants matured and were examined. There were grown the next year the progenies of 21 plants of which 7 only proved to be hybrids. Seven is 0.18% of 3,774. On this basis and if it is assumed that reciprocal crosses are equally likely to occur, the extent of natural crossing which occurred in the varietal experiments in 1923 and which caused genetic contamination was 0.36%.

SEGREGATION OF COLOR OF SEED-COAT

It has been stated that no plant was considered a natural hybrid unless its progeny showed segregation with respect to seed-coat color and other plant characters. The single F_1 plant which resulted from a natural cross in 1922 produced progeny with seed-coat colors as follows: 15 black, 29 mottled, and 4 yellow.

In 1923, two natural crosses occurred in Ito San, two in Ohio 9100, one in Elton, and two in U. S. 36647. The segregation with respect to seed-coat color of the progenies of the eight F_1 plants is shown in Table 3. The color classes marked "mottled" contain plants which exhibited a considerable variation in coloring but in each case the two predominating colors are indicated.

TABLE 3.—*Segregation of the progenies of natural F_1 hybrids with respect to seed-coat color.*

Variety in which cross occurred	Year cross occurred	Seed-coat colors of progeny					
		Black	Brown	Green	Yellow	Black and green mottled	Black and yellow mottled
Elton	1922	15			4		29
Elton	1923				18		7
Ito San	1923			16	4		
Ito San	1923				13	16	
Ohio 9100	1923				11	6	
Ohio 9100	1923				20	6	
U. S. 36647	1923	11	22	20	32		
U. S. 36647	1923	1	10	35	14		

CONCLUSIONS

A limited amount of natural crossing occurs in soybeans.

Under the conditions described in this paper the extent of natural crossing which produced varietal contamination was 0.14% in 1922 and 0.36% in 1923.

CORRELATIONS AND YIELD IN BREAD WHEATS[1]

H. B. SPRAGUE[2]

The subject of yield in wheat, and the factors affecting it, is very old and probably has been under observation since the advent of cultivated varieties. The problem has in general three phases, *viz.*, (a) determining what types, varieties, and strains are best adapted to certain environmental and cultural conditions, (b) producing new varieties by crossing and selection, and (c) determining just how the various environmental and cultural factors affect the growth and yield of a given variety or strain. The investigation here reported deals with some features of the third phase, particularly the correlations between morphological characters with respect to yield of grain and straw in three pure strains of common bread wheat.

HISTORICAL

Variation and correlation in cereals have been widely discussed in the past few decades and the use of the various statistical constants has thrown considerable light on the subject of yield. Organic correlations have been variously classified by different workers. East (6)[3] makes two groups, *viz.*, (a) somatic and (b) gametic. These correspond to the genetic and non-genetic groups of Conner (4). Love and Leighty (14) have further classified somatic correlations as (a) fluctuating or (b) stable, depending on their behavior under different environmental conditions. The correlations presented in this article are of the somatic type and both fluctuating and stable correlations are found.

Love (12) made a correlation study of peas, buckwheat, and corn with soils varying in fertility, and also (13) of the large and small grain question. Atkinson (3) gives data on eight spring wheat populations and Roberts (19) on three pure strains of wheat during two years. Meyers (15) measured the effect of fertility on variation and correlation in Dawson's golden chaff wheat. Whitcomb (22) compared correlations in barley, handling the data in two different ways. Parker (16) observed a high correlation between lengths of internode and the rachis of an English variety of wheat. Love and Leighty (14) and Leighty (11) studied variation and correlation in

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[3] Reference by number is to "Literature Cited," p. 995.

oats. Detzel (5) observed the relationship between the general morphological structure of the wheat plant and the forms of the minor plant parts. Grantham and Groff (8) made a study of the conditions causing sterile spikelets in the wheat spike. Arny and Garber (1) observed variation and correlation in wheat with special reference to the weight of seed planted. Grantham (7), Prescott (18), and Smith (20) devoted their attention to the phenomenon of tillering in wheat. Kiesselbach and Sprague (10) measured morphological characters and yield in wheat grown under a variety of environmental and cultural conditions.

In general these workers observed that means, standard deviations, and coefficients of variability are greatly affected by environmental and cultural conditions, and these changes are often much greater within a particular strain than are the differences between strains. Both variation and correlation, as measured by the various coefficients, appeared to decrease as the fertility of the soil diminished. For the most part, data were obtained from spaced plants and so are not representative of the crop grown under normal field conditions, where the plants are not spaced but are grown in drilled rows. Although fluctuating and stable correlations were observed by Love and Leighty, they did not offer a reason for either type. In some cases, coefficients were determined with the total values per plant as the unit of comparison, and in others, averages per plant or per tiller were the units used. Correlations were approximately the same, whether made between characters of main culms of plants or between averages per culm of plants; and in some cases correlations of total values per plant, with other total values, were nearly identical with correlations between averages and averages. Rather large differences in coefficients of correlation occurred in the same variety when plants were spaced and when grown in the drilled row.

Wheat plants tillered much more profusely when space planted than when drilled in the row. An abundance of mineral nutrients and moisture increased tillering, although there was considerable difference in the inherent ability of various varieties and strains of a crop to respond to these conditions. Adverse environmental and cultural conditions reduce both vegetative growth and yields of grain, but have more effect on straw yields than on grain yields. Grain yield of wheat is an expression of the number of kernels per spike, the average weight per kernel, and the number of spikes per plant, or per unit of area.

Correlations between plant yield and the average value per tiller of any character varied greatly when the work of various investigators was examined. Likewise, the correlations between the total values per plant of any character and average values were not constant. When totals per plant were correlated with other totals, such as plant yield, correlations were usually high. The correlations found when average culm length is one of the measures were fluctuating.

EXPERIMENTAL PROCEDURE

Since most of the work has been done on space planted grain, whereas in field production grain is regularly planted in drilled rows, it seemed advisable to investigate this subject from the more practical standpoint, using a unit of area as a basis rather than individual plants. With that end in view, Red Rock and Kanred wheat were grown and harvested at New Brunswick, N. J., in 1924 and 1925. Kanred wheat was also obtained from regularly planted fields at Lincoln, and North Platte, Nebraska, through the kindness of Dr. T. A. Kiesselbach and G. F. Sprague of those stations. Plants from 36 1-foot sections of drill row were harvested separately in each case. No account was taken of individual plants, the culm being cut as near the surface of the ground as possible in harvesting. After curing, the following data were obtained: Number of fertile tillers per unit of area, culm length, spike length, number of fertile spikelets and total spikelets per spike, and number of grains per spike. Total grain and straw yields were obtained from each 1-foot section. Culm length was taken to be from the ground level to the base of the lowest spikelet. Spike length was measured from the base of the lowest spikelet to the tip of the lemmas on the terminal spikelet, but did not include the awns. Straw yields per foot section were obtained by subtracting grain weight from the total weight. Averages per foot section were made of culm length, spike length, number of fertile spikelets, percentage of total spikelets which were fertile, weight per grain, grain yield per spike, and straw yield per culm.

The soil used at New Brunswick was a shallow phase Sassafras silt loam underlaid at about 2 feet with Penn shale. Four hundred pounds of a 2-12-2 fertilizer were applied per acre. This soil is medium in fertility and the rotation followed is corn, corn, spring grain, wheat, and timothy. At Lincoln, the soil used was Marshall silt loam, a typical loessial soil. At North Platte, Holdrege very fine sandy loam was used. No fertilizer was used at the last two stations. The topography was nearly level at all three stations. The rate of seeding was 5 pecks per acre in all cases, except at North Platte where 4 pecks were used. Drill rows were uniformly 7 inches apart. The date of seeding was nearly the same in each case since all three stations have nearly the same latitude, seeding taking place the latter part of September or very early in October. In general, the cultural conditions were nearly identical at all three stations, the soils were of medium fertility, and the principal differences were climatic.

A detailed comparison of the climatic conditions for the two crop seasons at the three stations is given in Table 1. The greatest difference shown is in the precipitation. The 1924 crop season at New Brunswick was one of plentiful moisture, but the 1925 crop season was markedly deficient for that region, both during the fall when tillering was taking place and in late spring when heading of the plant and filling of the kernels occurred. Lincoln had about two-thirds as much rainfall in 1925 as New Brunswick, and North Platte about two-fifths as much. The mean temperatures were nearly the same for all three stations, but the extremes were much greater for Lincoln and North Platte. Relative humidity in New Jersey was slightly higher for the 1924 crop season than for 1925. The atmosphere at Lincoln was considerably drier for the 1925 season than was that of New Jersey, but at North Platte it was still drier than at Lincoln. Wind velocities were nearly the same at Trenton and Lincoln, but only about three-fourths as high at North Platte as at Lincoln. The hours of sunshine were greatest at North Platte and least in New Jersey.

That these climatic conditions affected the mean values of the wheat characters measured will be noted in Table 2. Red Rock, a soft red variety commonly held to be adapted to humid conditions, profited by the moist weather of 1924; while Kanred, a hard red variety adapted to drier regions, produced the least grain that year of any of the yields reported. Straw yields varied in the same direction as grain yields, but the ratio of grain to straw varied from 1.45 for Kanred at Lincoln in 1925 to 3.59 for Red Rock at New Brunswick in 1925. Tillering for both varieties was greater in 1925 than in 1924 at New Brunswick. The low yield of the 1925 crop of Red Rock was due principally to the decrease in average weight of kernel, since the number of grains per spike and the number of tillers per unit of area were slightly greater for that year. The higher yield of Kanred for 1925 at New Brunswick over that of 1924 was attained by a considerable increase in tillering with a slight increase in average kernel weight. The yields of Kanred at Lincoln and North Platte were much higher than at New Brunswick for 1925 because of a large increase in number of grains per spike and an increase in their average weight, these more than balancing the reduction in tillering

TABLE 1.—*Climatic data for the winter wheat crop seasons of 1924 and 1925 at three stations.*[a]

		Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	
						Precipitation						Total
New Brunswick, N. J. . .	1924	3.87	4.22	2.12	4.06	5.03	4.12	2.29	5.92	6.08	3.19	40.90
New Brunswick, N. J. . .	1925	5.18	0.28	1.53	2.38	3.62	2.21	3.17	2.80	2.94	2.01	26.12
Lincoln, Nebr.	1925	0.95	1.90	0.42	1.98	0.64	1.93	1.39	1.46	0.89	6.74	18.30
North Platte, Nebr.	1925	1.66	0.95	0.08	1.81	0.07	0.51	0.22	1.78	1.92	1.46	10.46
						Monthly mean temperature						Mean
New Brunswick, N. J. . .	1924	67.8	53.8	43.3	41.5	32.6	28.0	38.8	48.8	56.6	66.6	47.8
New Brunswick, N. J. . .	1925	62.0	54.4	42.5	32.7	27.1	37.5	43.9	51.6	57.9	74.7	48.4
Lincoln, Nebr.	1925	62.4	61.6	43.4	19.9	22.7	33.2	43.4	59.5	60.6	74.3	48.1
North Platte, Nebr.	1925	60.5	56.8	39.6	15.2	20.2	35.7	42.8	54.7	59.5	71.7	45.7
						Mean relative humidity at noon						Mean
Trenton, N. J.	1924[b]	59	58	66	66	57	58	55	52	67	67	60.5
Trenton, N. J.	1925[b]	69	50	54	58	66	66	64	55	59	55	59.6
Lincoln, Nebr.	1925	48	37	46	72	72	65	48	44	44	53	52.9
North Platte, Nebr.	1925	52	45	39	72	68	53	39	39	46	45	49.8
						Average wind velocity						Average
Trenton, N. J.	1924[b]	8.2	11.2	11.2	11.2	14.5	12.6	15.4	13.0	13.1	8.6	11.9
Trenton, N. J.	1925[b]	10.8	8.6	10.9	8.2	11.8	10.0	11.8	10.6	9.9	9.9	10.3
Lincoln, Nebr.	1925	9.6	10.1	11.2	10.5	8.7	9.4	11.5	11.5	10.0	12.1	10.5
North Platte, Nebr.	1925	6.7	7.4	7.6	7.3	6.2	6.9	9.3	8.5	7.4	7.9	7.5
						Total hours of sunshine						Total
Trenton, N. J.	1924[b]	242	230	162	150	185	170	254	263	241	243	2,140
Trenton, N. J.	1925[b]	199	279	192	134	140	179	239	243	291	325	2,221
Lincoln, Nebr.	1925	217	247	227	143	194	190	276	268	324	300	2,386
North Platte, Nebr.	1925	259	250	209	131	216	192	261	288	309	362	2,477

[a] Data taken from U. S. Weather Bureau reports.

[b] Data for New Brunswick not available. Trenton is the nearest station recording such data.

TABLE 2.—*Mean values of measures of Kanred and Red Rock wheat for the crop seasons of 1924 and 1925.*

Characters measured	New Brunswick, N. J.				Lincoln, Nebr.	North Platte, Nebr.
	Red Rock		Kanred		Kanred	Kanred
	1924	1925	1924	1925	1925	1925
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Number of spikes per foot of drill row	24.9	26.1	39.0	44.4	31.5	33.8
Culm length (inches)	43.4	40.2	36.1	35.0	18.8	18.0
Spike length (inches)	2.77	2.88	1.92	2.20	2.39	2.85
Fertile spikelets per spike	8.58	9.13	7.51	7.80	10.21	11.76
Sterile spikelets per spike	5.94	6.34	6.14	8.05	3.81	4.64
Total spikelets per spike	14.52	15.47	13.65	15.85	14.02	16.40
Percent spikelets fertile	59.1	59.0	55.0	49.2	72.8	71.7
Grains per spike	14.68	15.37	11.52	11.00	18.18	18.65
Average weight per grain (grams)	0.0366	0.0243	0.0183	0.0200	0.0244	0.0223
Grain yield per spike (grams)	0.535	0.374	0.224	0.220	0.445	0.417
Straw yield per culm (grass)	1.438	1.343	0.660	0.774	0.647	0.667
Grain, bushels per acre	36.57	26.79	23.93	26.77	38.45	38.70
Straw, pounds per acre	5,899.4	5,773.8	4,232.0	5,653.3	3,355.6	3,715.6
Ratio of spike to culm length as 1 to	15.7	14.0	18.8	15.9	7.9	6.3
Fertile spikelets per inch of culm	0.198	0.227	0.208	0.223	0.543	0.653
Total spikelets per inch of culm	0.335	0.385	0.378	0.453	0.746	0.911
Grains per inch of culm	0.338	0.382	0.319	0.314	0.967	1.036
Fertile spikelets per inch of spike	3.10	3.17	3.91	3.55	4.27	4.13
Total spikelets per inch of spike	5.24	5.37	7.11	7.20	5.86	5.75
Grains per inch of spike	5.30	5.34	6.00	5.00	7.61	6.54
Grains per fertile spikelet	1.71	1.68	1.53	1.41	1.78	1.59
Ratio of grain to straw as 1 to	2.69	3.59	2.95	3.52	1.45	1.60
Total number of spikes measured	897	940	1,402	1,597	1,134	1,218

which accompanied the lower rainfall. Length of spike, number of spikelets, and kernels per spike increased with a reduction in rainfall, but culm length decreased with such a reduction.

METHOD STUDY

The number of grains per spike is dependent on the total number of fertile spikelets and the grains borne by each spikelet and so these characters should be correlated to some degree. Also, it seems reasonable to expect that some relation should exist between weight per grain and the number of kernels per spike. Furthermore, grain yield per spike is an expression of the number of kernels per spike and their average weight; and grain yield per unit of area is an expression of the number of fertile spikes and the yield per spike. The relationship existing between these and other plant characters is best expressed by the correlation coefficient, since it gives a definite mathematical expression of the degree with which any two of these characters vary simultaneously in the same or opposite directions.

In determining what relations exist between such characters, it is desirable to make the problem as simple as possible. It is practically impossible to determine such measures as the weight of each individual kernel or the weight of the grain produced by each spike for a very large number of spikes with the facilities available to most workers. Even if it were possible to obtain individual values, it is worthwhile to know if the process of handling the data cannot be greatly shortened. Various workers have used different units of comparison, but the advisability of using any certain unit has not been adequately discussed.

The questions arising in this study are: Should total values of a character per unit of area be correlated with other totals or should averages only be used? What will be the reliability of a correlation between a set of total values and a set of average values? Can correlations determined by any of these methods be expected to approximate coefficients obtained by considering each individual culm or spike as a unit, and if so, which method is the most reliable?

The correlations given in Table 3 were calculated from the 1924 crop of Kanred wheat to answer these questions. In every case, the correlations between total values of a character per unit of area and other total values were very high, no matter what the character considered. Correlations between totals and the average values of a character per tiller per unit of area, using the same plant characters as before, were very erratic, the correlation coefficients ranging from 0.709 to 0.153. The correlations obtained by using averages of

TABLE 3.—*Methods of obtaining correlation of coefficients using the same wheat in each instance.*

Variety Kanred, 1924 crop.

Population	Characters correlated	r.	P. E. ±
36 1-foot sections of drill row	Total length of culms per foot of drill row, vs:		
	Total length of spikes per foot	.988	.003
	Total number fertile spikelets per foot	.958	.009
	Total number grains per foot	.896	.022
	Total length of spikes per foot drill row, vs:		
	Total number fertile spikelets per foot	.959	.009
	Total number grains per foot	.919	.017
	Total number fertile spikelets per foot drill row, vs:		
	Total number grains per foot	.989	.002
36 1-foot sections of drill row	Total length of culm per foot drill row, vs:		
	Average length of spikes per foot	.336	.100
	Average number fertile spikelets per spike per foot	.205	.108
	Average number grains per spike per foot	.150	.110
	Total length of spikes per foot drill row, vs:		
	Average number fertile spikelets per spike per foot	.709	.056
	Average number grains per spike per foot	.178	.109
	Total number fertile spikelets per foot drill row, vs:		
	Average number grains per spike per foot	.413	.093
36 1-foot sections of drill row	Average length of culm per foot drill row, vs:		
	Total length of spikes per foot	.153	.110
	Total number fertile spikelets per foot	.581	.074
	Total number grains per foot	.620	.069
	Average length of spikes per foot drill row, vs:		
	Total number fertile spikelets per foot	.575	.075
	Total number grains per foot	.657	.064
	Average number fertile spikelets per spike per foot, vs:		
	Total number grains per foot	.558	.077
36 1-foot sections of drill row	Average length of culm per foot drill row, vs:		
	Average length of spike per foot	.710	.056
	Average number fertile spikelets per spike per foot	.693	.058
	Average number grains per spike per foot	.657	.064
	Average length of spike per foot drill row, vs:		
	Average number fertile spikelets per spike per foot	.864	.028
	Average number grains per spike per foot	.835	.034
	Average number fertile spikelets per spike per foot drill, vs:		
	Average number grains per spike per foot	.989	.002
1,402 individuals, those obtained from 1-foot sections used above	Culm length, vs:		
	Spike length	.715	.009
	Number fertile spikelets per spike	.728	.008
	Number grains per spike	.767	.007
	Spike length, vs:		
	Number fertile spikelets per spike	.825	.006
	Number grains per spike	.717	.009
	Number fertile spikelets per spike, vs:		
	Number grains per spike	.939	.002

characters per tiller per unit of area for both subject and relative measures gave results practically as reliable as those obtained by using individual measures of the tillers, and the time required for calculation was greatly reduced. This method of handling the data gives mean values of the characters as in other methods, but standard deviations and coefficients of variability are for the units of area and, therefore, are not comparable with such constants obtained by treating each culm or spike as an individual. The extremes of variation are much wider when individuals are used than when averages per unit of area are the basis of measurement. Table 4 illustrates this difference.

TABLE 4.—*Comparison of standard deviations when individual tiller characters and averages per foot section of drill row of these are used as units.*

Kanred, 1924 crop.

Characters measured	Unit, individual spike or culm	Unit, average per foot of drill row
Culm length (inches)............	4.34	1.75
Spike length (inches)............	0.225	0.075
Number fertile spikelets per spike.	2.11	0.758
Number grains per spike........	4.51	1.53

In addition to indicating the most reliable method of obtaining coefficients, Table 3 throws some light on the widely dissimilar results obtained by various workers in correlating plant characters. When total values per tiller per unit of area are correlated with other totals the coefficients are uniformly high because the effect is much like that obtained when a series of values are correlated with an identical series. To get total values per unit of area, one must multiply the average value per tiller by the number of tillers, and thus one is correlating the number of tillers with itself, the measures of the tiller characters varying so slightly in comparison that they have little effect on the correlation coefficient. When plants are the units used, the same effect would be produced by correlating totals with totals; except that the fewer the tillers per plant, the more nearly such coefficients would approach those obtained by using individual tillers as units of comparison. When total values per unit of area or per plant are correlated with averages, very erratic results will be obtained because of the disturbing influence of the number of tillers, and such correlations will never exhibit stability. Correlations made using total values as one or both of the measures are often not only of little value but may actually lead one to draw faulty conclusions as to the relation between plant characters.

Calculation of the correlations was found to be greatly shortened when Phillips'(17) short method of obtaining a Pearson coefficient of correlation was used.

DISCUSSION OF CORRELATION DATA

A. RED ROCK AND KANRED WHEAT

The correlation data here presented were obtained by using the average per tiller per unit of area of the various characters measured. They do not permit an accurate study of the effect of any spike or culm character on the total grain or straw yield per unit of area, but do show the relation existing between such characters on the tiller basis. They do not permit a study of tiller characters on total yield, because under ordinary field conditions the number of tillers per foot of drill row varies considerably, due to the uneven distribution of seed and the various losses of plants which occur after germination as a result of the environmental complex. Such variations in number of tillers do not mean, however, that the soil beneath shows an equivalent distribution of roots. Arny and Hayes (2), Kiesselbach (9), and Weaver (21) have shown that the roots of each plant extend laterally at least 1 foot on all sides of the plant and probably farther when space permits. Thus, all the soil resources are rather uniformly used and the culms from one section are, on the whole, not more vigorous than those of any other section nearby. For this reason the relation between grain yield per unit of area and any tiller character is to be obtained accurately only when the average number of tillers per unit of area is considered. The data on Nebraska No. 60 wheat permit such a study and will be discussed later.

The correlation coefficients determined between the various characters measured and their probable errors are given in Table 5. The number of spikes per foot of drill row was never highly correlated with any tiller character and these correlations were very unstable. If coefficients must be three times as large as their probable errors before being considered significant, then only those above 0.300 would be considered as such in Table 5. These correlations involving number of tillers are insignificant because the variation in number of tillers does not mean that there is an inverse variation in the volume of soil from which to draw nutrients. Because of the wide spread of the individual tiller root system and the consequent intermingling of the roots from tillers as far away as 1 or 2 feet, tillers from a sparsely occupied foot have no advantage, if surrounded by areas with normal stands. In two cases, Red Rock 1925 and Kanred, North Platte 1925, this group of correlations, although small in value, were nearly all negative. This indicates that when tillering is generally repressed by unfavorable conditions and subsequently the conditions are favorable for plant growth, the individual tillers increase considerably in size. Normally, however, the plant utilizes the available resources by increasing the number of tillers rather than by any great increase in size of the component parts of each tiller.

Kiesselbach and Sprague (10) have shown that, normally, the tillers of Turkey Red Wheat are formed during the fall and early spring months, but that the stems remain greatly shortened and the spikes undifferentiated until about April 1. After April 1, spike development begins and by April 30, the flowers may be distinguished in the spikelets. The spike and its spikelets and flowers continue to develop, so that the spike emerges about June 1. Fertilization soon follows and maturity is reached in an additional 30 days. In the two cases noted in the preceding paragraph tillering was hindered by dry weather in the fall and winter, but the moisture supply was more nearly adequate in the spring and early summer.

The correlations between culm length and any of the other characters measured are fluctuating. Those between average straw yield per culm and average culm length were the only exceptions, being comparatively stable and fairly significant. This was more apparent for Kanred than for Red Rock. Culm length was always significantly correlated with spike length, but the coefficients varied from 0.308 to 0.710. Culm length was also significantly correlated with the number of fertile spikelets per spike in four cases out of six, but the coefficients varied from 0.143 to 0.693. The relation of culm length to the percentage of all spikelets which were fertile was practically the same as between culm length and the number of fertile spikelets per spike, but the coefficients were slightly higher (0.235 and 0.783). Correlations between culm length and number of grains per spike also varied considerably, but were significant and fairly high in four cases out of six. Culm length was significantly correlated with average weight per kernel at Lincoln and North Platte, but not at New Brunswick for either variety or crop season. Culm length was more closely related to grain yield per spike on Kanred wheat than on Red Rock, ranging from 0.557 to 0.802 on Kanred and falling to 0.422 and 0.426 on Red Rock.

From these data it seems clear that conditions modifying the length and number of internodes do not necessarily cause a corresponding change in the development of the other parts of the tiller. Culm length is an expression of the number of internodes and their average length. Either or both of these characters may be considerably changed without changing the total dry weight produced. Plant physiologists have long recognized that plant height is not an

TABLE 5.—*Summary of correlations made on characters of Red Rock and Kanred wheat.*

	New Brunswick, N. J.				New Brunswick, N. J.				Lincoln, Nebr.		North Platte, Nebr.	
	Red Rock, 1924		Red Rock, 1925		Kanred, 1924		Kanred, 1925		Kanred, 1925		Kanred, 1925	
	r.	P. E.	r.	P. E.	r.	P. E.	r.	P. E.	r.	P. E.	r.	P. E.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Number spikes per foot of drill row, vs:		±		±		±		±		±		±
Average culm length	.488	.086	— 063	.112	.408	.004	.242	.106	.463	.088	.004	.112
Average spike length	—.098	.111	—.314	.101	.296	.102	—.167	.109	.216	.107	—.179	.109
Average number fertile spikelets per spike	.003	.112	—.361	.098	.026	.112	.091	.111	.209	.107	—.192	.108
Average percentage spikelets fertile	.121	.111	—.291	.103	— 172	.109	.223	.107	.195	.108	—.112	.111
Average number grains per spike	.130	111	—.362	.098	.061	.112	.133	.110	.155	.110	—.214	.107
Average weight per grain	242	.106	—.110	.111	399	.095	—.048	.112	.379	.096	.064	.112
Average grain yield per spike	.586	.074	—.324	.101	.168	.109	053	.112	.307	.102	—.011	.112
Average straw yield per culm	—.059	.112	—.284	.103	.318	.101	— 165	.109	.341	.099	—.152	.110
Average culm length, vs:												
Average spike length	.384	.096	.647	.065	.710	.056	.462	.088	.309	.102	.308	.102
Average number fertile spikelets per spike	.143	.110	.636	.067	693	.058	.588	.074	.275	.104	.585	.074
Average percentage spikelets fertile	.235	.106	.596	.072	.620	.069	.636	.067	.272	.104	.783	.043
Average number grains per spike .	.265	.105	.592	.073	.657	.064	.605	.071	.293	.103	.709	.056
Average weight per grain	.320	.101	—.200	.108	.133	.110	.294	.103	.764	.047	.654	.064
Average grain yield per spike	.422	.092	.426	.092	.627	.068	.743	.050	.557	.078	.802	.040
Average straw yield per culm	.573	.075	.673	.061	.876	.026	.702	.057	.637	.067	.799	.041
Average spike length, vs:												
Average number fertile spikelets per spike .	.979	.005	.921	.017	.864	.028	.691	.059	.953	.010	.836	.034
Average percentage spikelets fertile.	.874	.027	.863	.029	.745	.050	.512	.083	.826	.036	.713	.055
Average number grains per spike ...	.928	.016	.882	.025	.835	.034	.670	.062	.950	.111	.759	.048
Average weight per grain....	—.083	.112	.008	.112	.297	.102	.070	.112	.204	.108	.062	.112

Average grain yield per spike	.647	.065	.750	.049	.846	.032	.597	.072	.805	.040	.545	.079
Average straw yield per culm	.804	.040	.915	.018	.831	.035	.793	.042	.692	.059	.595	.073
Average number fertile spikelets per spike, vs:												
Average percentage spikelets fertile	.983	.004	.974	.006	.905	.020	.953	.010	.868	.028	.767	.046
Average number grains per spike	.987	.003	.979	.005	.989	.022	.939	.013	.959	.009	.967	.007
Average weight per grain	—.249	.105	—.193	.108	.245	.106	—.112	.111	.312	.101	.246	.106
Average grain yield per spike	.682	.060	.844	.032	.939	.013	.698	.058	.802	.040	.757	.048
Average straw yield per culm	.660	.063	.906	.020	.788	.043	.655	.064	.740	.051	.797	.041
Average percentage spikelets fertile, vs:												
Average number grains per spike	.973	.006	.960	.009	.897	.002	.898	.022	.915	.018	.855	.030
Average weight per grain	—.130	.110	.075	.112	.066	.112	—.110	.111	.263	.105	.531	.081
Average grain yield per spike	.695	.058	.832	.035	.743	.050	.667	.062	.821	.037	.825	.036
Average straw yield per culm	.639	.067	.873	.027	.683	.060	.562	.077	.675	.061	.789	.042
Average number grains per spike, vs:												
Average weight per grain	—.166	.109	.126	.111	.102	.111	—.027	.112	.215	.107	.404	.094
Average grain yield per spike	.686	.060	.887	.024	.866	.028	.735	.052	.860	.029	.868	.028
Average straw yield per culm	.793	.042	.854	.030	.763	.047	.653	.064	.774	.045	.876	.026
Average weight per grain, vs:												
Average grain yield per spike	.589	.073	.561	.077	.478	.087	.635	.067	.693	.058	.799	.041
Average straw yield per culm	.000	.112	—.022	.112	.267	.104	.278	.104	.609	.071	.654	.064
Average grain yield per spike, vs:												
Average straw yield per culm	.614	.070	.729	.053	.704	.057	.754	.048	.896	.022	.928	.016

accurate indicator of growth. The results obtained in this study further bear out that conclusion. Differences in temperature, moisture supply, intensity and quality of radiant energy, mineral nutrient supply, and the character of the surrounding gases all have a profound effect on the total growth of the plant, but variation of them may cause considerable morphological change without much change in total dry weight produced.

When Red Rock and Kanred were grown under conditions unsuited to their optimum development, correlations were more nearly perfect between culm and spike length than when conditions were more favorable A comparatively dry spring permitted greater grain yields of Kanred, but Red Rock produced the most when there was more rainfall. According to Kiesselbach and Sprague, the number of internodes has already been determined before the spikelets have been differentiated in the prinordia of the spike, so that environmental conditions may favor the development of one character and hinder the other. The elongation of internodes takes place largely after the total number of spikelets has been determined, and so here again conditions may not favor maximum development of both culm and spike characters because of the time interval involved. It appears that this may be the reason for the fluctuating correlations between culm length and spike length, and also between culm length and the component parts of the spike.

The correlations between culm length and grain yield do not fluctuate as widely as those between culm length and the other spike characters, but they still could not be classed as stable. Grain yield depends not only on the amount of materials synthesized by the tiller, but also on the efficiency with which this material is translocated to the developing kernel. Warm sunshiny days combined with a moderate supply of moisture in the soil and air favor this translocation. Since at least part of the synthesis and all of the translocation of materials take place after the culms are fully elongated, it is not surprising that culm length and grain yield per spike show no constant relation. The moderately high correlations between straw weight per culm and culm length indicate that the amount of materials synthesized by the tiller is more closely related to its length than to any of the spike characters.

Correlations between spike length and all of the other characters measured, except number of tillers and culm length, are fairly stable with one minor exception. The number of fertile spikelets per spike is very closely correlated with spike length. Likewise, the number of grains per spike is closely correlated with spike length. The percentage of spikelets which were fertile is not quite so closely correlated with spike length as the other two characters just mentioned, but these correlations would still be rated as high. It is quite evident from these correlations that spike length is determined by the component spikelets; and that all four characters, spike length, number of fertile spikelets, percentage of spikelets fertile, and grains per spike, are dependent upon the same set of growing conditions. All of these characters are developed at about the same time on any one tiller and, therefore, the time factor does not enter.

Spike length shows no significant correlation with weight per grain, indicating that either (a) conditions which favor long spikes do not favor filling of the kernels or (b) that the development of spike length and the filling of the kernels are so widely separated in the development of the tiller with respect to time that growing conditions have changed in the interval between the two periods.

Correlations between spike length and grain yield per spike were moderately high, the coefficient ranging from 0.545 to 0.846. Spike length is more closely related, however, to straw yield per culm as shown by coefficients from 0.595 to 0.915. Long spikes are therefore a fairly good indication of large grain and straw yields per culm. An extremely close correlation could not be expected in either case, since much synthesis of materials and all translocation takes place after the component spike parts are formed. Spike length is determined during the months of April and May only, while yields are built up over the entire period of growth.

The high, positive, and stable correlations between number of fertile spikelets, percentage of spikelets fertile, and number of grains per spike are further evidence that all three of these phases of development are benefited by the same conditions and are rather closely associated in time. None of these three characters showed a significant relation to the average weight per grain. This is very likely due to the difference in time when these parts develop. Kernel weight is largely dependent on conditions during the 30 days just previous to harvest, all of this period occurring after the spike parts have been determined.

The correlations between these three closely related characters, number of fertile spikelets, percentage of spikelets fertile, and grains per spike, and grain yield per spike are fairly high and stable, the coefficients all falling between 0.655 and 0.887. Likewise, the correlations between these three characters and straw yield per culm fall between 0.639 and 0.906. These characters are as closely related to yields as would be expected considering the time interval involved in the development of each, yields being the result of development during the total growth period of the tiller, and the spike parts of but two months of that period.

It will be noted that weight per grain is never significantly correlated with any of the characters measured, except grain and straw yields per tiller. The correlations between weight per grain and grain yield per spike were always significant and fairly stable, the coefficients ranging from 0.478 to 0.799. Since there is no relation between weight per grain and grains per spike, and since both are factors in determining grain yield per spike; it appears that both of these characters are of about equal importance in influencing yield. The number of grains per spike might reasonably be expected to show some relation to weight per grain, since the amount of material available for moving into the kernels is somewhat limited, and the greater the number of kernels present, the smaller would be the amount available for each. However, this does not seem to be the case. Evidently, conditions affecting translocation are much more important in determining the weight of the kernel than the total amount of materials available. This observation is substantiated by the correlations between weight per grain and straw yield per culm. In only two cases were such correlations significant, namely, those on Kanred at North Platte and at Lincoln. In both cases growing conditions produced low straw yields and high grain yields per tiller. At both stations conditions were present which favored a maximum amount of translocation of materials from the rest of the tiller to the kernels At New Brunswick, 1924 and 1925, the sunshiny weather and moderate supply of moisture in soil and air were lacking, and therefore, no significant correlations between kernel weight and culm weight were obtained on either Kanred or Red Rock.

The observation just made as to the effect of environmental conditions on the translocation of materials to the kernel and the resulting relationship between weight per grain and straw yield per culm is further borne out by the correlations between grain and straw yield per tiller. Those for Kanred 1925 at North Platte and Lincoln, are the highest of this group of correlations, these coefficients being 0.928 and 0.896, respectively, while those for Kanred and Red Rock at New Brunswick for the two years fell between 0.614 and 0.754. One may conclude that when the proper conditions for translocation of materials prevail, the correlation between grain yield per spike and straw yield per culm is nearly perfect. Whenever such conditions do not prevail, the relationship is not so close; and the more unfavorable are the conditions for translocation, the lower will be correlation coefficients between grain and straw yield per tiller.

Correlations between grain and straw yields of Red Rock and Kanred were somewhat higher for 1925 than for 1924, showing that the two varieties behave in much the same way, even though Red Rock is commonly considered to be well adapted to humid conditions and Kanred is considered well adapted to the subhumid conditions represented by the central portion of Kansas. The reason for the difference in adaptation must then be due to some other character or characters than those considered above. The ability to survive severe winters is undoubtedly responsible for part of this difference, as shown by the tests of various experiment stations. Tillering ability is probably responsible for the rest of the adaptation. Varieties may differ greatly in the efficiency of their photosynthetic processes and in their response to the stimuli of mineral nutrients, moisture, radiant energy, and the rest of the environmental complex. These differences are expressed in the ability to form new tillers under a certain set of conditions, and to mature them normally. The data contained in Table 2 indicate that Kanred tillered much more freely at New Brunswick than did Red Rock. The exact reason for this difference is not known. These data (Table 2) also show that the ratio of grain to straw per tiller is largely determined by the growing conditions rather than by the varietal difference in the type of physiological behavior.

B. NEBRASKA NO. 60 WHEAT

As stated above, the effect of tillering on yields and tiller characters can be determined when the average number per unit of area for a given treatment is considered rather than the number on each individual unit. Therefore, the data on Kanred and Red Rock wheat will not give a true measure of the effect of tillering, either on individual tiller characters or on yields of grain and straw per unit of area.

Data collected on wheat grown in the vicinity of Lincoln, Nebr., for the years 1921 and 1922 lend themselves to a study of the effect of tillering on yields and tiller characters. The variety used was Nebraska No. 60, similar to Kanred in being a hard red winter selection and adapted to much the same climatic and soil conditions. The samples were all collected from the various experimental plat and field tests conducted by Dr. T. A. Kiesselbach at the Nebraksa Agricultural Experiment Station and under his kind supervision. Ten 1-foot sect'ons in the drill row were selected at random from each treatment. The 10 sections so obtained were treated as a single sample representative of that particular treatment. Measurements,

TABLE 6.—*Data obtained from Turkey Red (Nebraska No. 60) wheat grown at Lincoln, Nebr., 1921 and 1922.*

Year	Treatment[a]	Spikes per 10 feet of drill row	Average culm length, inches	Average spike length, inches	Number fertile spikelets: spike	Percentage spikelets fertile	Number of grains per spike	Weight per grain, grams	Grain yield per 10 feet of drill row, grams	Grain yield per spike, grams	Straw yield per 10 feet of drill row, grams	Average culm weight, grams
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1921	Field long cropped to alfalfa	488	29.2	2.48	10.28	71.6	17.79	0.0246	213.7	0.438	431.3	0.884
1921	Field long cropped to grain	251	21.8	2.12	8.41	70.7	15.00	0.0278	105.0	0.418	177.0	0.705
1921	No treatment	424	28.5	2.57	10.95	77.4	20.20	0.0271	231.8	0.547	408.2	0.963
1921	No treatment	429	26.8	2.47	10.38	76.9	18.98	0.0269	219.0	0.510	361.0	0.841
1921	No treatment	407	28.1	2.48	10.38	76.2	18.67	0.0245	186.2	0.457	328.8	0.808
1921	No treatment	413	28.6	2.50	10.54	76.2	19.13	0.0266	210.3	0.509	359.7	0.893
1921	4 tons manure per acre	456	29.3	2.54	10.71	76.9	19.63	0.0272	243.5	0.534	446.5	0.979
1921	8 tons manure per acre	450	28.4	2.47	10.44	75.3	18.88	0.0268	228.0	0.507	402.0	0.893
1921	16–0–0	512	28.1	2.50	10.27	73.8	18.56	0.0240	228.0	0.445	447.0	0.873
1921	0–16–0	438	27.2	2.54	10.60	76.0	19.17	0.0256	215.2	0.491	384.8	0.879
1921	0–0–16	396	26.1	2.46	10.22	75.1	18.35	0.0271	197.0	0.497	353.0	0.891
1921	16–16–4	426	26.6	2.54	10.37	76.5	18.92	0.0261	210.5	0.493	365.9	0.859
1921	4–16–4	418	26.7	2.42	9.98	76.1	18.15	0.0268	203.3	0.486	346.7	0.829
1921	8–32–8	430	26.4	2.41	9.80	73.6	17.43	0.0262	196.0	0.456	339.0	0.788
1921	12–48–12	547	26.1	2.46	9.64	70.4	16.22	0.0245	217.0	0.397	413.0	0.755
1921	Rates of 3 pecks per acre	286	23.2	2.09	8.97	69.2	15.80	0.0261	117.8	0.412	194.2	0.679
1921	seeding 5 pecks per acre	346	21.1	1.84	7.68	65.6	12.80	0.0240	106.0	0.306	194.0	0.561
1921	8 pecks per acre	366	20.3	1.73	6.96	62.5	11.47	0.0224	94.2	0.257	190.8	0.521
1921	Spring Heavily pastured	282	21.7	2.25	8.87	69.0	15.47	0.0249	108.5	0.385	183.5	0.651
1921	pasturing Not pastured	320	25.7	2.24	9.22	73.3	16.72	0.0272	145.7	0.455	244.3	0.763

1921	Dates of	Sept. 16, 1920	409	24.2	2.39	10.09	73.5	17.96	0.0261	191.5	0.468	311.5	0.762
1921	seeding	Sept. 22, 1920	383	24.9	2.45	10.43	76.3	18.86	0.0261	188.5	0.492	303.5	0.792
1921		Oct. 1, 1920	342	24.7	2.56	11.03	76.6	19.60	0.0250	167.5	0.490	277.5	0.811
1921		Feb. 15, 1921	194	25.0	2.97	12.10	77.6	20.17	0.0161	63.0	0.325	149.0	0.768
1922		Sept. 16, 1921	289	28.6	2.90	11.46	72.9	20.29	0.0229	134.5	0.465	263.5	0.912
1922		Sept. 22, 1921	308	29.8	2.80	11.14	71.7	19.45	0.0242	145.0	0.471	270.0	0.877
1922		Oct. 1, 1921	287	30.2	3.04	12.37	75.8	21.77	0.0210	131.0	0.456	276.0	0.962
1922		Feb. 15, 1922	185	19.8	3.00	11.64	78.4	21.23	0.0195	76.5	0.414	163.5	0.884
1922		Oct. 16, 1921	213	26.0	3.04	13.01	81.1	23.12	0.0189	93.0	0.437	192.0	0.901
1922	Rate of	3 pecks per acre	365	34.3	2.63	10.93	71.2	18.37	0.0279	187.0	0.512	353.0	0.967
1922	seeding	5 pecks per acre	444	33.9	2.68	10.55	71.5	19.07	0.0250	212.0	0.477	418.0	0.941
1922		8 pecks per acre	458	33.1	2.50	9.61	68.2	16.87	0.0239	184.5	0.403	379.5	0.829
1922	Method of	Broadcasted	232	35.5	3.16	14.70	78.0	23.44	0.0264	143.5	0.619	230.5	0.993
1922	seeding	Drilled	380	34.6	2.77	10.91	74.0	18.94	0.0251	180.5	0.475	391.5	1.030
1922	Field long cropped to alfalfa		415	34.1	2.90	10.84	71.0	19.47	0.0229	185.0	0.446	373.0	0.899
1922	Field long cropped to grain		273	28.0	2.53	9.19	67.2	15.59	0.0281	119.5	0.438	220.5	0.808

[a]Except where indicated, the rate of seeding was 5 pecks per acre; the formulae give pounds per acre of NH_3, P_2O_5, and K_2O.

TABLE 7.—*Correlations made on Turkey Red wheat (Nebraska No. 60) grown at Lincoln, Nebr., under various environmental conditions.* Crops of 1921 and 1922[a]

	Grain yield per foot of drill row	Grain yield per spike	Spikes per foot of drill row	Culm length	Spike length	Fertile spikelets per spike	Percentage of spikelets fertile	Grains per spike	Weight per grain	Straw yield per culm
Grain yield per spike	.604 ±.071									
Spikes per foot of drill row	.889 ±.024	.190 ±.108								
Culm length	.462 ±.088	.571 ±.076	.280 ±.104							
Spike length	— 034 ±.112	.459 ±.089	—.303 ±.102	546 ±.079						
Fertile spikelets per spike	.030 ±.112	.597 ±.072	—.290 ±.103	.515 ±.084	.926 ±.016					
Percentage of spikelets fertile	.230 ±.106	.628 ±.068	—.114 ±.111	.132 ±.110	.626 ±.068	.764 ±.047				
Grains per spike	.149 ±.110	.660 ±.063	—.201 ±.108	.470 ±.088	.906 ±.020	.963 ±.008	.859 ± .029			
Weight per grain	.573 ±.075	.536 ±.080	.425 ±.092	.166 ±.109	—.431 ±.092	—.321 ±.101	—.147 ±.110	—.276 ±.104		
Straw yield per culm	.460 ±.089	.777 ±.045	.122 ±.111	.766 ±.046	.776 ±.045	.728 ±.053	.622 ±.069	.815 ±.040	.077 ±.112	
Straw yield per foot drill row	.958 ±.009	.494 ±.085	.899 ±.022	.570 ±.076	.045 ±.112	.064 ±.112	.167 ±.109	.164 ±.109	.408 ±.094	.537 ±.080

[a] The measurements, counts, and weights used are in every case averages per 10 feet of drill row.

counts, and weighs were obtained as described for Kanred and Red Rock except that the 10 sections were treated as one unit. The mean values obtained in this manner are given in Table 6.

The mingling of data for two crop years in obtaining correlation coefficients seems justified in this instance, because climatic differences and crop years have had little effect on the correlations computed for Kanred and Red Rock wheats. The only exceptions to this statement were the correlations between weight per grain and (a) culm length and (b) straw yield per culm.

Table 7 gives the correlation coefficients obtained from the data given in Table 6. As with Kanred and Red Rock, the number of tillers shows little or no correlation with the development of individual spikes on Nebraska No. 60. Average weight per grain shows a low positive correlation with number of tillers, but it is doubtful if this is important. Correlations involving culm length are very similar to those of Kanred and Red Rock. Also, the correlations on Nebraska No. 60 involving spike length, number of fertile spikelets per spike, percentage of spikelets fertile, and grains per spike fall within the variations in coefficients observed on the two varieties mentioned.

In general, it may be said that the data on Nebraska No. 60 show the same behavior for this variety as for Kanred and Red Rock when compared on the basis of tiller performance. This gives added weight to the conclusion that adaptation is expressed, at least in part, by tillering ability and not as any notable difference in the relation between tiller characters. The insignificant correlation between kernel weight and straw yield per culm is undoubtedly due to the inclusion of data from different dates of seeding. The later seedings were ripened somewhat prematurely in both 1921 and 1922 and thus are comparable with Kanred at New Brunswick where climatic conditions did not favor an optimum amount of translocation of storage materials.

The data for Nebraska No. 60 are particularly valuable because they permit the calculation of correlations between either grain or straw yields per unit of area and the various tiller characters. As stated above, only data giving the average number of tillers per unit of area are reliable for a study of yields per unit of area. It should be remembered, however, that the stability of such correlations cannot be determined without results from several similar sets of data. The differences between correlations involving grain yield per spike and those involving grain yield per unit area, are due to the entrance of the tillering factor.

Grain yield per foot of drill row is seen to be very closely correlated with the average number of tillers producing fertile spikes, having a coefficient of 0.889 (Table 7). It is also quite significantly correlated with grain yield per spike (0.604), indicating that both factors are important. The correlation between grain yield per unit of area and grains per spike is insignificant (0.149), but grain yield versus average kernel weight gave a coefficient of 0.573. It is evident that any method of forecasting the yielding ability of a variety which includes but one of the three characters, viz., number of tillers, grains per spike, and average weight per grain, may be very unreliable. Even when all three are considered, yields do not follow a set rule or formula so far devised in these studies. One of the three characters may be repressed as a result of climatic or cultural conditions, but total yields may actually be higher, due to higher values of the other two characters. Among other methods, that of least squares was used in trying to devise a formula to forecast yield using the three factors given above, but it proved to be very unsatisfactory when applied to any of the data at hand and so is not presented here.

It is of interest to note that the correlation between grain and straw yield per unit of area is very close (0.958). This does not, however, show the true physiological relation existing between the two characters. This relation is shown more accurately when the yields are compared on the basis of individual tillers and proves to be somewhat lower (0.777) than when totals per unit of area are compared. This result is identical with that to be expected in the light of the method of study discussed above (Table 2).

Straw yield per unit of area, like grain yield, is closely correlated with the average number of fertile spikes or tillers (0.899). Straw yield per unit of area is also significantly correlated with the average straw yield per culm (0.537), but the number of spikes is the more important of the two characters, judging from the magnitude of the correlation coefficients. As in the case of grain yields, the true physiological relation between straw production and other characters of the tiller is obtained when the average straw yield per tiller is correlated with averages of the other character under consideration, and not when total straw yields per unit of area is correlated with the averages of a character.

GENERAL DISCUSSION AND CONCLUSIONS

The study of these three varieties of wheat under normal field conditions indicates that physiological processes and the morphological development of all three are very similar when compared on a tiller basis, even when grown in widely different climates. Whether or not this is true of all varieties remains to be shown, but it seems likely that it is true of the winter bread wheats at least. Varieties differ in the efficiency with which they can assimilate materials and synthesize plant food under a particular set of conditions, and this may be in a large measure responsible for the difference in tillering ability.

New tillers are developed as a result of the physiological activities of the plant and these in turn increase the amount of materials synthesized. Apparently, the individual tiller soon begins to lead an existence somewhat independent of its immediate parent, but lives in competition with neighboring tillers for moisture, nutrients, and radiant energy. There is much difference in the size of the various tiller characters between varieties and also between samples of the same variety grown under different conditions, but this does not affect the relation existing between physiological processes of the individual tillers as shown by their morphology.

The value of correlations between morphological characters and yield has been rather generally accepted in some quarters in the breeding and selection of desirable varieties of cereals, but it seems desirable to remember that such correlations may be quite different when made with the spaced plant as the unit of comparison from those made with the same variety grown under field conditions in the drilled row because of the difference in amount of tillering. If correlations are made between characters using averages per tiller in both cases, results will be dependable and stable. If, however, total values per plant or per unit of area are used, it should be remembered that the number of tillers has then become a disturbing factor and should be recognized as such. The ability of a certain variety to form tillers when grown as spaced plants is very likely to be different from its ability to tiller when in close competition with other plants. It is data of the second class which are of most value to the grower of grain. For example, spaced plants may show a high correlation between the number of tillers producing mature spikes and grain yields per spike, but if a like correlation does not exist when plants are grown in the drill row in competition with other plants, it is not desirable to select high yielding spikes in an attempt to produce a high yielding strain. In any case, the correlations must prove to be fairly stable before they can be used with any degree of accuracy. The unreliable results obtained when a formula involving the number of spikes and the factors expressed as grain yield per spike is used in predicting grain yielding ability indicate that probably the best method of selecting desirable strains is still that of actual field testing over a period of years, using the best obtainable field plat technic.

SUMMARY

Data have been gathered from three varieties of bread wheat (Red Rock, Kanred, and Nebraska No. 60) grown in different climatic regions and crop years. In contrast to the bulk of similar previous investigations, the crops were grown in the drilled row with normal rates of seeding and a unit of area was used as the basis of comparison. In each case, all the possible correlation coefficients were calculated between the following characters: Number of fertile spikes per foot of drill row, culm length, spike length, number of fertile spikelets per spike, percentage of total spikelets which were fertile, grains per spike, weight per grain, grain yield per spike, and straw yield per spike. Correlation coefficients were also calculated on Nebraska No. 60 between grain and straw yields per unit of area and the other characters listed above. A physiological explanation of the various correlations is given and their application to breeding and selection work is suggested.

1. Thirty-six units of area furnished the data for each variety at each station. Correlations between averages of the characters per culm or spike, per unit of area, gave approximately the same coefficients as those obtained by using individual culm or spike characters as the basis of comparison.

2. Yields per acre and the means of the culm and spike characters varied widely with climatic conditions and variety.

3. More favorable conditions for growth resulted in a larger number of tillers per unit of area or in an increase in the size of the individual tillers without influencing greatly the correlations existing between tiller characters.

4. Correlations between the tiller characters measured, except those involving culm length or weight per kernel, were fairly stable, regardless of the variety considered or where it was grown.

5. Correlations between culm length and other tiller characters, except straw yield per culm, fluctuated widely, but without definite relation to any climatic data available for the crops used. Average weight per kernel is highly correlated with straw yield per culm only when climatic conditions favor normal ripening.

6. The following correlations were high, positive, and fairly stable: (A) Between spike length and (a) number of fertile spikelets per spike, (b) percentage of spikelets fertile, and (c) grains per spike; (B) between fertile spikelets per spike and (a) percentage of spikelets fertile and (b) grains per spike: and (C) between percentage of spikelets fertile and grains per spike.

7. The following correlations were intermediate in value, positive, and fairly stable: (A) Between grain yield per spike and (a) spike length, (b) fertile spikelets per spike, (c) percentage of spikelets fertile, (d) grains per spike, (e) weight per grain, and (f) straw yield per culm; and (B) between straw yield per culm and (a) spike length, (b) fertile spikelets per spike, (c) percentage of spikelets fertile, and (d) grains per spike.

8. The following correlations were always insignificant or very low in value· (A) Between weight per kernel and (a) spike length, (b) fertile spikelets per spike, (c) percentage of spikelets fertile, (d) grains per spike, and (e), in five cases out of seven, straw yield per culm.

9. Grain yield per unit of area of Nebraska No. 60 wheat shows: (A) A high positive correlation with (a) average number of spikes and (b) straw yield per unit of area; (B) an intermediate positive correlation with (c) grain yield per spike and (d) weight per kernel; (C) a low positive correlation with (e) culm length and (f) straw yield per culm; and (D) an insignificant correlation with (g) spike length, (h) fertile spikelets per spike, (i) percentage of spikelets fertile, and (j) grains per spike. No assurance of the stability of this group of correlations is given.

10. Straw yield per unit of area of Nebraska No. 60 wheat shows: (A) A high positive correlation with (a) average number of culms; (B) an intermediate positive correlation with (b) culm length and (c) straw yield per culm; (C) a low positive correlation with grain yield per spike and (e) weight per kernel; and (D) an insignificant correlation with (f) spike length, (g) fertile spikelets per spike, (h) percentage of spikelets fertile, and (i) grains per spike. No assurance of the stability of this group of correlations is given.

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A RECESSIVE GLABROUS CHARACTER IN SOYBEANS[1]

RALPH T. STEWART AND JOHN B. WENTZ[2]

Soybeans (*Soja max*) are normally pubescent. Piper and Morse (2),[3] however, report that a number of smooth varieties exist in Japan, and it is known to the writers that some strains of glabrous plants exist in the United States, but so far as they have been able to learn none have been reported in this country.

A glabrous character (P) in soybeans has been reported by Nagai and Saito (1) which is inherited as a simple Mendelian dominant. These authors presented data from F_3 and F_4 generation hybrids to show the dominant condition. In their work they obtained the glabrous plant from a cross between two pubescent plants. In the F_2 generation they noticed a plant which was glabrous, and explained the origin of the glabrous character as a factor mutation in one of the flowers of the F_1 plants.

The authors of this paper have found in their work a glabrous character very similar to the one referred to above, but which is inherited as a recessive. Since the character found in this work behaves exactly opposite to the one found by Nagai and Saito, it seems desirable to present the data obtained in these observations.

DESCRIPTION OF THE GLABROUS CHARACTER

In this new type of soybean which is being designated as p_2 there seems to be no pubescence present, but with the aid of a small hand lens short fine hairs can be detected. The glabrous plants are much smaller than the pubescent plants, and produce only a very small number of pods. The leaves are much smaller than the leaves of normal plants and show a crinkled and dwarfed condition. Figs. 1, 2, and 3 are photographs of normal and glabrous plants of the same family.

SOURCE OF MATERIAL

In cross No. 50 "Soysota x Ogemaw" reported by Wentz and Stewart (3), three hybrid seeds were obtained. From these three F_1 plants were produced, all of which were pubescent. The F_1 plants were given the numbers 50–1, 50–2, and 50–3. In the spring of 1924, 100 seeds from numbers 50–1 and 50–2 were planted in the field. During the summer it was noticed that the progeny of No.

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[1] Contribution from the Department of Farm Crops, Iowa State College, Ames, Iowa. Received for publication July 1, 1926.

[2] Graduate Assistant and Associate Professor, respectively.

[3] Reference by number is to "Literature Cited", p. 1009.

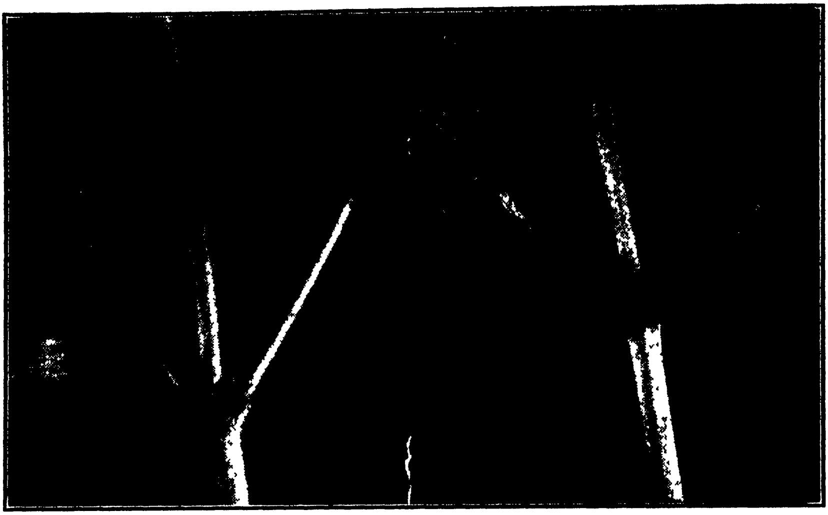

FIG. 1.—These two plants are the progeny of the same F_2 pubescent plant segregating for the glabrous and pubescent characters. The plant to the left is a normal pubescent plant and the one to the right a glabrous plant. Note the long stiff hairs on the pubescent plant and the very short fine hairs on the glabrous plant. Magnified X 3".

(Photographs by Dr. J. N. Martin, Botany Department, Iowa State College, Ames, Iowa.)

50–2 consisted of both glabrous and pubescent plants, and that all plants of the progeny of No. 50–1 were pubescent.

The original cross for this material was made by William T. H. Ho[4] during the summer of 1922 in the variety test plats. Seed was obtained from the female plant and was found to breed true for the pubescent character. Seed from the male parent was lost and no records except the general variety characteristics are available to show the character of the male parent. No glabrous plants have ever been noticed at this station before. It was thought, however, that since two of the F_1 plants were pure for pubescence and the other segregated that the male parent may have been heterozygous for the glabrous character. A random sample of the male variety was taken and the seed tested in the greenhouse. No glabrous plants were found among 2,821 individuals. The facts that no glabrous plants have ever been noticed at this station before, and that no glabrous plants have been found in either of the parental varieties indicate that the character very likely arose from a mutation in the germ cells of one of the parents.

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[4] Graduate student, Iowa State College.

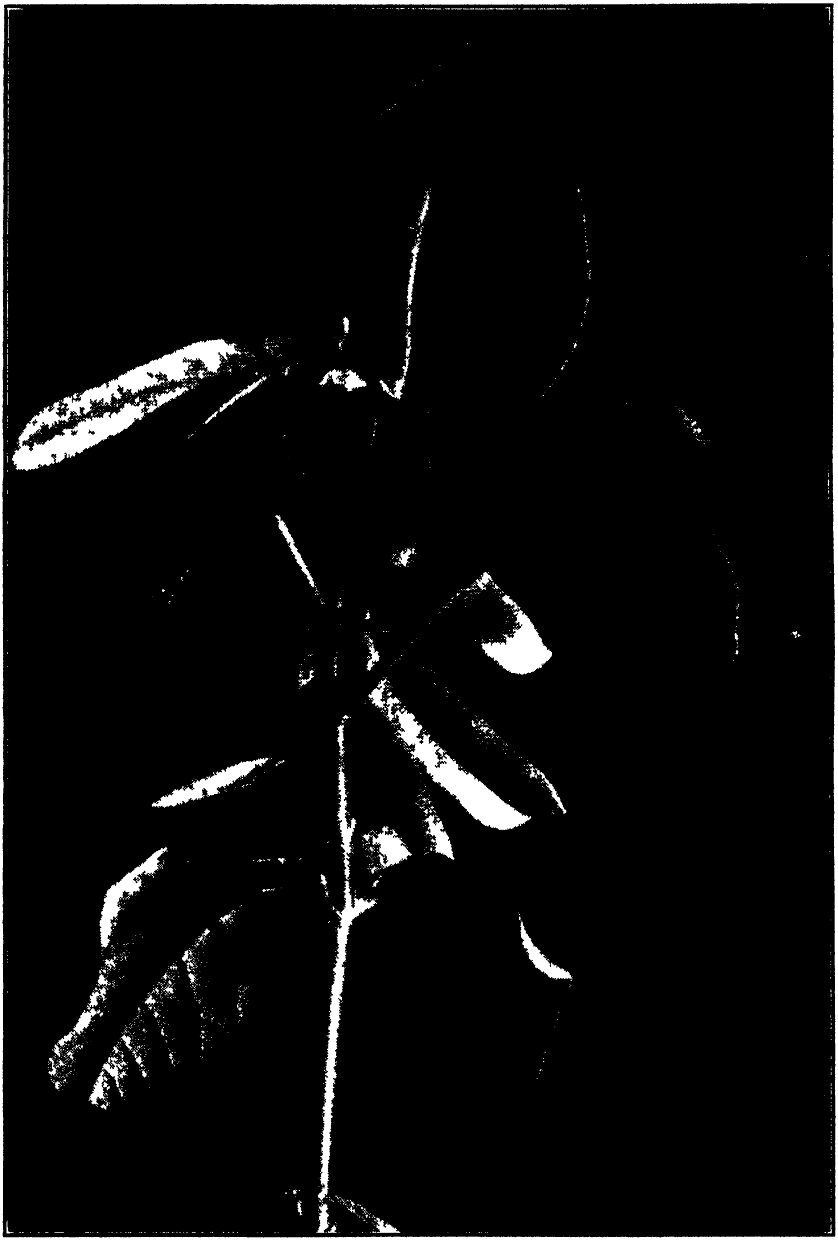

FIG 2 —Normal F_3 plant from an F_2 pubescent plant segregating for the glabrous and pubescent characters Note the hairs on the stem, leaves, and pods, also the size of the pods Compare this plant with plant shown in Fig 3. Both plants were grown in the greenhouse Normal size

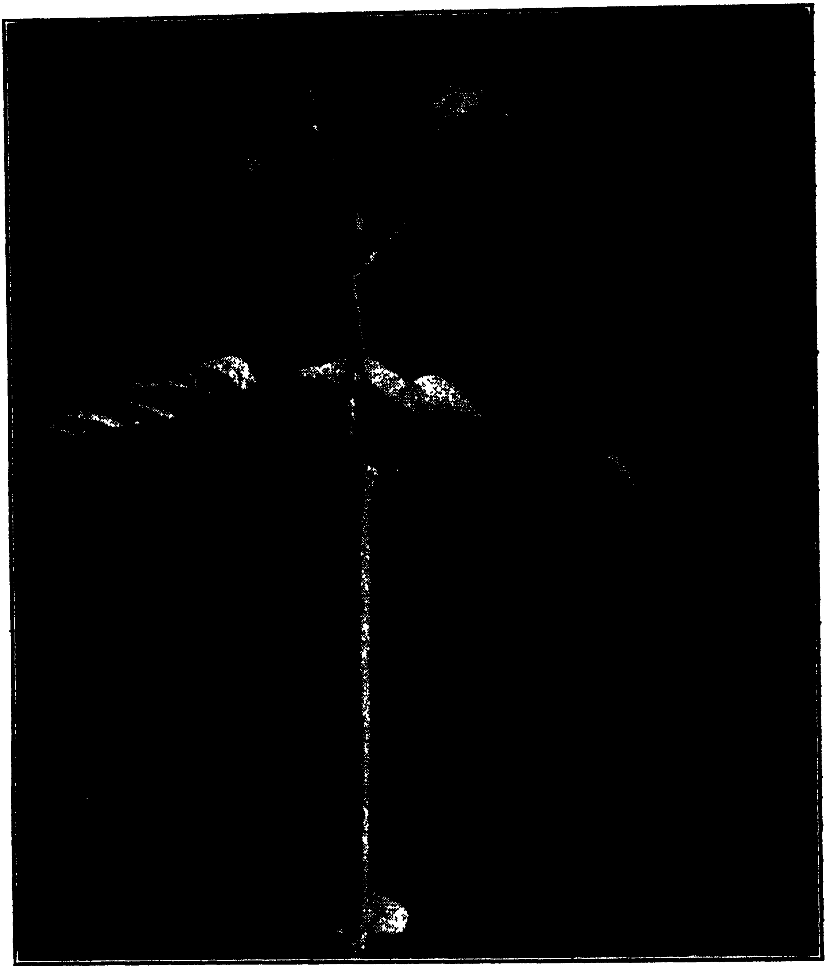

FIG. 3.—Glabrous plant from the same F_2 pubescent plant as the one shown in Fig. 2. Note the absence of hairs, also the absence of pods. This plant is the same age as the plant shown in Fig. 2. A peduncle is shown at the second node. The flowers have aborted and fallen off. This plant later produced one pod containing one seed.

RESULTS

From the F_1 plant No. 50-2 which was found to be segregating for glabrousness 87 plants were obtained, 75 of which were pubescent and the remaining 12 glabrous.

During the winter of 1924 and 1925, 50 more seeds from No. 50-2, 48 seeds from No. 50-3, and seed from 69 of the F_2 pubescent and 11 of the glabrous plants were tested in the greenhouse. From the 50

TABLE 1.—*Showing the progeny from F_2 pubescent plants segregating for the glabrous character.*

F_2 plant No.	Observed Pubescent	 Glabrous	Deviation from 3:1 ratio	P. E.	$\frac{\text{Deviation}}{\text{P. E.}}$
3	14	2	2.00	1.17	1.71
4	92	27	2.75	3.19	0.86
11	78	24	1.50	2.95	0.51
13	68	19	2.75	2.72	1.01
17	72	29	3.75	2.94	1.28
19	81	30	2.75	3.08	0.89
20	62	11	7.25	2.50	2.90
25	183	55	4.50	4.51	1.00
28	136	51	4.25	3.99	1.07
30	81	23	3.00	2.98	1.01
41	8	2	0.50	0.92	0.54
43	21	2	3.75	1.40	2.68
45	37	15	2.00	2.11	0.95
47	42	14	0.00	2.19	—
50	113	33	3.50	3.53	0.99
64	97	30	1.75	3.29	0.53
65	30	9	1.75	1.82	0.96
69	105	31	3.00	3.41	0.88
70	9	2	0.75	0.97	0.77
77	5	3	1.00	0.82	1.22
80	79	25	1.00	2.98	0.33
81	60	23	2.25	2.66	0.85
Total	1473	460	23.25	12.84	1.81
Expected 3:1	1449.75	483.25			

TABLE 2.—*Showing the breeding behavior of F_3 pubescent plants.*

F_2 plant No.	Number of F_3 plants Heterozygous	 Pure	Deviation from expected 2:1 ratio	P. E.	$\frac{\text{Deviation}}{\text{P. E.}}$
3	5	2	0.33	0.84	0.39
4	14	8	0.67	1.49	0.45
11	17	15	4.33	1.79	2.42
13	12	5	0.67	1.31	0.51
17	15	14	4.33	1.71	2.53
19	10	14	6.00	1.55	3.87
20	7	5	1.00	1.10	0.91
25	23	20	5.66	2.08	2.72
28	28	17	2.00	2.13	0.94
30	22	9	1.33	1.76	0.76
43	6	4	0.67	1.00	0.67
50	14	9	1.33	1.52	0.86
64	5	6	2.33	1.05	2.22
65	18	5	2.67	1.52	1.76
69	14	4	2.00	1.35	1.48
80	8	6	3.33	1.19	2.80
81	6	3	0.00	0.95	—
Total	224	146	22.67	6.10	3.72
Expected	246.67	123.33			

F_1 seeds from No. 50–2, 40 pubescent and 5 glabrous plants were obtained which, when added to the 87 plants produced in the field, made a total of 132 F_2 plants. Of these 132 F_2 plants, 115 were pubescent and 17 were glabrous, a ratio of 6.76:1. All of the plants from 50–3 were pubescent. Of the 69 F_2 pubescent plants tested 22 segregated for what was apparently a 3:1 ratio and 47 bred true for the pubescent character. One of the 11 glabrous F_2 plants (No. 53) produced 13 F_3 seedlings, 11 of which were glabrous and 2 pubescent; another (No. 54) produced 25 F_3 plants, 24 of which were glabrous and 1 pubescent. The remaining nine glabrous F_2 plants bred true. The pubescent plants failed to produce seed in the greenhouse and could not be tested, but for reasons which will be brought out later it is believed that the pubescent plants were due to natural hybridization or possibly mixture. From the 11 F_2 glabrous plants 132 F_3 plants were obtained, all of which were glabrous except the three mentioned above.

TABLE 3.—*Showing the totals of the F_4 progenies of segregating F_3 pubescent plants from 17 different F_2 families.*

F_2 plant No.	Observed Pubescent	Observed Glabrous	Deviation from 3:1 ratio	P. E.	Deviation / P. E.
3	70	21	1.75	2.79	0.63
4	397	135	2.00	6.74	0.30
11	298	109	7.25	5.89	1.23
13	144	62	10.50	4.19	2.51
17	207	84	11.25	4.98	2.26
19	259	86	0.25	5.42	0.05
20	84	27	0.75	3.08	0.25
25	658	145	55.75	8.28	6.73
28	1279	382	33.25	11.90	2.79
30	836	292	10.00	9.81	1.19
43	312	101	2.25	5.94	0.38
50	639	195	13.50	8.43	1.60
64	199	72	4.25	4.81	0.88
65	949	293	17.50	10.29	1.70
69	485	160	1.25	7.42	0.17
80	243	61	15.00	5.09	2.95
81	236	71	5.75	5.12	1.12
Total	7295	2296	101.75	28.60	3.56
Expected 3:1	7193.25	2397.75			

Table 1 shows the results for the 22 F_2 pubescent plants which were found to be segregating for the glabrous and pubescent characters. The data for each family conform closely enough to the theoretical 3:1 ratio; although in two families, No. 20 and No. 43, rather large deviations are shown. When the progenies of all the segregating families were taken together, 1,933 plants were obtained. Of these, 1,473 were pubescent and 460 glabrous. The numbers expected for a 3:1 ratio were 1,449.75:483.25, thus a deficiency of 23.25 in the number of glabrous plants was obtained. Seed from 17 of the 22 segregating F_2 plants was planted in the field to secure mature F_3 plants. Seeds from 370 pubescent and 62 glabrous plants from this F_3 generation were planted in the greenhouse during the winter of 1925 to 1926 to secure the F_4 generation.

TABLE 4.—*Showing the progeny of F_3 glabrous plants which produced one or more pubescent plants in the F_4 generation.*

F_2 plant No.	F_3 plant No.	Number of pubescent plants	Number of glabrous plants	Total
4	28	1	4	5
11	4	1	13	14
11	9	2	14	16
11	11	2	3	5
11	15	2	4	6
13	1	1	12	13
13	15	1	10	11
17	6	1	9	10
17	26	2	5	7
20	4	2	7	9
20	10	3	10	13
20	12	1	6	7
25	13	1	7	9
25	17	1	3	4
28	1	2	10	12
28	16	2	3	5
28	22	3	12	15
28	23	2	4	6
30	7	1	8	9
30	10	1	9	10
30	25	3	14	17
30	35	2	9	11
64	1	2	15	17
64	6	1	13	14
65	29	3	10	13
80	4	1	8	9
80	14	1	6	7
Total		45	228	273

Table 2 shows the number of heterozygous and pure pubescent F_3 plants as determined by their breeding behavior in the F_4 generation for each of the 17 F_2 families tested. Here again, it will be noticed that there is a deficiency in the number of segregating pubescent plants, although it is not so marked as in the F_2 generation. From the 370 pubescent plants tested, 224 were heterozygous and 146 bred true. The expected on the basis of a single factor hypothesis (2:1

TABLE 5.—*Showing the breeding behavior in F_5 of the F_4 glabrous and pubescent plants from glabrous F_3 plants.*[a]

Plant No.	F_4 Generation Number of seed planted	Character of F_4 plant	Observed F_5 generation Number of pubescent plants	Number of glabrous plants
11- 4- 1	5	glabrous		5
- 2	5	glabrous		5
- 3	4	glabrous		4
- 4	3	glabrous		2
- 5	3	glabrous		3
- 6	3	glabrous		3
- 7	3	glabrous		3
- 8	4	glabrous		4
- 9	3	pubescent	1	2
-10	2	glabrous		2
-11	2	glabrous		1
-12	2	glabrous		2
-13	3	glabrous		2
11- 9- 1	3	glabrous		3
- 2	3	glabrous		3
- 3	3	glabrous		3
- 4	8	pubescent	6	2
- 5	2	glabrous		2
- 6	2	glabrous		2
- 7	2	glabrous		2
- 8	3	glabrous		3
- 9	4	glabrous		4
-10	9	pubescent	6	3
-11	3	glabrous		2
-12	3	glabrous		3
-13	4	glabrous		4
-14	3	glabrous		2
-15	1	glabrous		1
-16	2	glabrous		2
11-11- 1	4	glabrous		4
- 2	3	glabrous		3
- 3	3	glabrous		3
- 4	4	pubescent	4	0
- 5	6	pubescent	4	2
11-15- 1	4	glabrous		4
-2	3	glabrous		3
- 3	3	glabrous		2
- 4	6	pubescent	4	2
- 5	4	glabrous		4
- 6	4	pubescent	3	1
13- 1- 1	3	glabrous		3
- 2	3	glabrous		3
- 2a	6	pubescent	5	1

[a] All seed produced by each plant was planted. The low yields are due to the fact that the plants were grown in the greenhouse.

TABLE 5.—*Continued.*

Plant No.	F$_4$ Generation Number of seed planted	Character of F$_4$ plant	Observed F$_5$ generation Number of pubescent plants	Number of glabrous plants
– 3	3	glabrous		3
– 4	3	glabrous		3
– 5	4	glabrous		4
– 6	3	glabrous		3
– 7	4	glabrous		4
– 8	2	glabrous		2
– 9	4	glabrous		4
–10	3	glabrous		3
–11	4	glabrous		4
13–15– 1	6	glabrous		4
– 2	6	glabrous		6
– 3	3	glabrous		3
– 4	6	glabrous		6
– 5	5	glabrous		5
– 6	4	glabrous		4
– 7	3	glabrous		3
– 8	5	glabrous		5
– 9	4	glabrous		4
–10	4	glabrous		4
–11	2	pubescent	2	0
17– 6– 1	6	glabrous		3
– 2	5	glabrous		3
– 3	5	glabrous		5
– 4	5	glabrous		3
– 5	5	glabrous		5
– 6	3	glabrous		3
– 7	6	pubescent	3	3
– 8	6	glabrous		6
– 9	3	glabrous		3
17–26– 1	3	glabrous		3
– 2	3	glabrous		2
– 3	5	glabrous		5
– 4	5	glabrous		4
– 5	6	pubescent	5	1
– 6	5	pubescent	4	1
– 7	5	glabrous		5
20– 4– 1	6	glabrous		6
– 2	4	glabrous		2
– 3	4	pubescent	3	0
– 4	4	pubescent	2	2
– 5	4	glabrous		3
– 6	3	glabrous		3
– 7	4	glabrous		3
20–10– 1	4	pubescent	3	1
– 2	2	glabrous		2
– 3	3	glabrous		3

TABLE 5.—*Continued.*

	F_4 Generation		Observed F_5 generation	
Plant No.	Number of seed planted	Character of F_4 plant	Number of pubescent plants	Number of glabrous plants
- 4	2	glabrous		2
- 5	3	pubescent	3	0
- 6	4	glabrous		4
- 7	1	pubescent		1
- 8	4	glabrous		4
- 9	6	glabrous		6
-10	3	glabrous		3
-11	3	pubescent	2	1
-12	4	glabrous		4
-13	2	glabrous		2
20-12 - 1	2	glabrous		2
- 2	3	glabrous		3
- 3	3	glabrous		3
- 4	3	glabrous		2
- 5	2	pubescent	2	0
- 6	2	glabrous		2
- 7	6	glabrous		6

ratio) was 246.67:123.33. The deviation (22.67) divided by the probable error (6.10) is 3.72 which is obviously not a very close fit.

Table 3 shows the results in the F_4 generation for all the segregating F_3 plants for each of the 17 F_2 families. In carrying out the experimental work, counts were made separately for each of the 224 segregating F_3 pubescent plants, but since the results for individual plants were not noticeably different from the total for each family, it was thought not necessary to present data from each plant separately. It will be noticed from the table that all of the 17 different families, except No. 25, conform fairly close to a 3:1 ratio. When the plants from all of the families are considered together there are 9,591 F_4 plants. Of these, 7,295 were pubescent and 2,296 glabrous. The deviation (101.75) divided by the probable error (28.60) is 3.56. Thus it is seen that here again as in each preceding case there is a considerable deficiency in the number of glabrous plants obtained.

As previously mentioned, 62 F_3 glabrous plants were tested in the greenhouse. Of the 62 glabrous plants, 27 produced one or more pubescent plants. The remaining 35 bred true for glabrousness. The results from the 27 glabrous plants which produced pubescent plants are presented in Table 4. All F_4 plants from the glabrous plants of families 11, 13, 17, and 20 were allowed to grow to maturity in the greenhouse and tested in the F_5. The results are shown in Table 5. It will be noticed from the table that all of the glabrous plants bred true for glabrousness and all of the pubescent plants except five

(11–11–4, 13–15–11, 20–4–4, 20–10–5, and 20–12–5) segregated. This shows that the pubescent plants were heterozygous and all the glabrous plants pure.

DISCUSSION

It is seen from the above results that pubescence is dominant to glabrousness, which is, as stated earlier, exactly opposite to the case reported by Nagai and Saito. Since the glabrous plant reported by these workers resembles the one studied here in all morphological characters, but behaves different genetically, one would at first suppose that they were the same character, and that possibly an inhibitor was present which caused the dominant character to act differently in this case. An inhibiting factor in this material would suppress the factor for glabrousness and cause it to act as a recessive. Likewise, an inhibiting factor in the material reported by Nagai and Saito would suppress the factor for pubescence and cause it to act as a recessive.

On the basis of an inhibiting factor and the glabrous character dominant as reported by Nagai and Saito, the above observations could be explained by assuming the F_1 plant to be heterozygous for the inhibitor. A heterozygous F_1 plant with the formula P_1 P_1 P_2 p_2 should produce in the F_2 generation three pubescent plants to one glabrous.[5] The actual observations were 115 pubescent to 17 glabrous or a ratio of 6.76:1. From the 69 F_2 pubescent plants tested, 48 should have been heterozygous if the inheritance is due to a single factor, but only 22 were found to segregate. If the F_1 plants were heterozygous for both factors (P_1 and P_2), then instead of a 3:1 ratio in the F_2 generation the ratio should have been 13 to 3, and instead of 48 of the 69 F_2 pubescent plants segregating only 31.86 should have segregated. Thus both the F_2 results and the progeny test fit closer to a 13:3 ratio than a 3:1, and since 2 of the 11 glabrous plants produced pubescent plants the writers developed the 13:3 hypothesis.

The F_3 results, however, fit a 3:1 ratio better than any other, and the same was found true in the progeny test of the F_3 pubescent plants and the F_4 generation. On the other hand, the F_3 glabrous plants produced several pubescent plants which indicated that several of the glabrous plants were heterozygous and further suggested a 13:3 ratio. If such were the case and the glabrous character is dominant, then the pubescent plants should have bred true and about two-thirds of the glabrous plants segregated in the F_5 generation. This, however, did not occur, but as shown in Table 5 every glabrous plant bred true and 13 out of 18 of the pubescent plants produced both glabrous and pubescent plants. The only simple explanation then for the occurrence of pubescent plants among the progeny of the glabrous plants is through mixture, or as suggested earlier in the paper, natural hybridization. Since the pods from all of these plants were carefully picked and hulled by hand, there was very little chance for mixture, and accordingly, natural hybridization is the most probable explanation. Further evidence that the pubescent plants were the result of natural hybridization lies in the fact that both parental varieties have brown seed-coats and two of the pubescent plants produced seed with different colored seed-coats, one with the black eyebrow pattern and the other yellow like the Ito San variety The one with the black eyebrow seed-coat produced two pubescent plants and one glabrous The one with the Ito San, or yellow seed-coat, produced 14 pubescent and 3 glabrous plants.

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[5] Here P_2 is used to indicate a factor which inhibits large P_1 (a dominant glabrous character) described by Nagai and Saito. If the glabrous type here studied is entirely different from the one reported by the above authors, then p_2 can be used to designate the new recessive glabrous character and P_2 the dominant pubescent condition.

The question naturally arises as to why natural hybridization did not occur among the F_4 plants as in the F_3. This, however, may be explained, since the F_3 plants were grown in the field scattered among thousands of pubescent plants and the F_4 plants were grown in the greenhouse where only 18 pubescent plants existed among 88 glabrous. Also, it is to be expected that more natural crossing should occur in the field than in the greenhouse where there are few insects and very little wind to carry the pollen.

Since most of the data conform closer to a 3:1 ratio than to any other and since none of the glabrous plants grown in the greenhouse proved to be heterozygous, the inheritance is interpreted as being due to a single pair of Mendelian factors. It has not been possible, however, to determine whether the glabrous character studied here is different from the one reported by Nagai and Saito or whether it is the same factor with an inhibitor causing it to behave as a recessive, but it is hoped that from further study of crosses which have been made on other varieties this will be possible.

The finding of the two pubescent plants with different seed-coat colors also helps to strengthen the conclusion that the character studied here is not the same as the one described by Nagai and Saito, since it shows that when crossed with two other varieties it acts as a recessive.

Natural hybridization in soybeans has been reported by Woodworth (4). Results of his experiments show that natural cross pollination does occur, but the percentage of natural crossing is very low, only about 0.16%. He concludes, however, that the amount may vary with the season, locality, and variety. The present experiment was not planned to determine the amount of natural crossing, but from the above results it is evident that a much greater percentage has taken place here than has been reported thus far. This brings up another point which may help to explain the deficiency in the number of glabrous and segregating pubescent plants. It has been noticed that although a comparatively large number of flowers is produced on the glabrous plants but few pods form. It appears then that there is something about the pollen, possibly infertile pollen or slow pollen tube growth, which causes the ovules not to become fertilized until the flowers are well open, and consequently a better chance is afforded for natural crossing. The same phenomena would also cause a deficiency in the number of glabrous and segregating pubescent plants.

SUMMARY

1. A glabrous character (p_2) is reported which is thought to have arisen from a mutation in the germ cells of one of the parents in a cross between two varieties of soybeans.

2. The inheritance seems to be due to a single pair of Mendelian factors, glabrousness being recessive. It has not been determined whether this character is different from the one reported by Nagai and Saito, or whether it is the same character with an inhibitor causing it to behave differently.

3. A larger amount of natural cross pollination was observed between normal and glabrous plants than has been reported in any previous soybean studies.

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PROGENY OF FOUR- AND FIVE-LOCK BOLLS PRODUCED ON THE SAME MOTHER COTTON PLANT[1]

HENRY DUNLAVY[2]

In the breeding of cotton the plant is naturally the unit of selection rather than the individual boll. Many growers are of the opinion that by selecting the large, five-lock bolls for seed they will be able to improve the quality of their cotton. Such growers fail to realize that the massing together of all the bolls from a number of superior plants is better than the massing of superior bolls from mediocre plants. The only reason for rejecting certain bolls of a selected plant is that poorly matured bolls will produce seed of low vitality.

In connection with this problem the writer has collected data in the study of progeny rows from individual bolls. In 1921 and 1924 the breeding blocks contained "boll progeny rows" planted from seed of self-fertilized four- and five-lock bolls from the same parent plant. This gave an ideal opportunity to study the heritability of four- and five-lock bolls from the same plant. Tables 1 and 2 give the result of this work.

TABLE 1.—*Percentage of five-lock bolls produced on an individual mother plant, together with the percentage of five-lock bolls produced on progeny rows from four- and five-lock bolls of this individual plant.*

Grown at Waxahachie, (North) Texas. Variety—Watson Acala.

	1920 mother plant selection	1921 boll progeny row Percentage of five-lock bolls produced from seed of a Five-lock boll	 Four-lock boll
	87.2	64.6	64.7
	83.3	58.3	50.0
	86.7	62.5	64.3
	82.4	83.3	73.9
	68 7	64.8	71.4
	94 5	84.3	83.3
	85.1	70.6	85.2
	69.7	59.7	58.9
	61.1	47.8	55.2
	84.1	70.8	62.5
Average	80.3	66.7	66.9

The results of these two years' work show that there is very little difference between the five-lock boll production of the progeny of a four- and five-lock boll from the same mother plant. Both years, however, the four-lock boll progeny proved to be a slightly higher producer of five-lock bolls. In 1921 the difference was 0.2%, while

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[1] Contribution from the S. Maston Nixon Co., Robstown, Texas. Received for publication August 2, 1926.

[2] Cotton Breeder.

TABLE 2.—*Percentage of five-lock bolls produced on an individual mother plant, together with the percentage of five-lock bolls produced on progeny rows from four- and five-lock bolls of this individual plant.*

Grown at Robstown, (South) Texas. Variety—Blue Wagon (Mebane).

	1923 mother plant selection	1924 boll progeny row Percentage of five-lock bolls produced from seed of a Five-lock boll	Four-lock boll
	61.5	14.9	27.6
	63.2	26.6	22.2
	62.5	34.4	30.8
	45.5	20.7	23.6
	68.7	22.8	29.5
	66.6	21.6	25.0
	38.4	21.0	26.2
	46.7	25.9	27.0
	52.6	20.5	16.7
	37.5	22.7	21.8
	69.2	25.0	18.1
	42.9	17.4	31.7
Average	54.6	22.8	25.0

in 1924 it was 2.2% in favor of the mother four-lock boll. In 1921 it will be seen that the progeny of four-lock bolls produced the highest percentage of "fives" 5 times out of 10, or 50.0%, while in 1924 the proportion was 7 out of 12, or 58.3%.

HERITABILITY OF FIVE-LOCK BOLLS AS SHOWN BY AVERAGES OF PROGENIES OF "HIGH" AND "LOW" MOTHER PLANTS

In each case it was found that the highest producing (production of five-lock bolls) plants resulted in the highest producing progenies. The "high" progeny group in 1921 was 9.0% greater than the "low," while in 1924 the corresponding difference was 1.9%.

TABLE 3.—*Averages of five highest and five lowest 1920 producing mother plants, together with respective 1921 progeny averages.*

	Average of five highest and five lowest plants in 1920	Average of production of the progenies of the same plants produced from a Five-lock boll	Four-lock boll	Average
	%	%	%	%
High	87.5	70.6	72.0	71.3
Low	73.0	62.8	61.9	62.3

TABLE 4.—*Averages of six highest and six lowest 1923 producing mother plants, together uith respective 1924 progeny averages.*

	Average of six highest and six lowest plants in 1923	Average of production of the progenies of the same plants produced from a Five-lock boll	Four-lock boll	Average
	%	%	%	%
High	65.3	24.2	25.5	24.8
Low	43.9	21.4	24.5	22.9

While the character of five-lock bolls is of relatively small importance, it is one that can be easily studied on account of its ability to be concretely expressed. The chief importance of the character is in its reaction on "boll size." From two years' work with Mebane cotton in the weighing of four- and five-lock bolls it has been found that the "five" is 1.04 grams, or 13.8%, heavier than the "four." Previous work with Acala in 1921 by the writer[3] has shown the corresponding difference to be 11.2%.

Some very useful work could be done to find out whether or not there is any correlation between "number of bolls per plant" and "percentage of five-lock bolls." This might have a bearing on yield.

The percentage of five-lock bolls is probably affected by climatic and soil conditions as much, if not more, than other characters.

[3] Frequency and importance of five-lock bolls in cotton. *In* Jour. Amer. Soc. Agron., 13:332-334. 1921.

A PRELIMINARY NOTE ON THE RELATION OF PHOTOSYNTHETIC CARBOHYDRATE TO NODULE FORMATION ON SOYBEANS[1]

LEWIS T. LEONARD[2]

Factors which stimulate or retard nodule formation on the roots of leguminous plants are many and varied, but considered as a whole the generally accepted opinion is that conditions which favor the growth of the host plant are favorable to the bacteria associated with it and *vice versa* It is the common understanding that the bacteria in the nodules, in their function of fixing atmospheric nitrogen utilize energy-forming materials in the form of carbohydrate produced through the process of photosynthesis. If then, the photosynthetic function is modified by lack of light, insufficient carbon dioxide, or a deficiency in chlorophyll, it is reasonable to expect that nitrogen fixation resulting from the activities of the nodule bacteria may be limited in a degree corresponding somewhat to the extent of the modification of the factors concerned.

It has been noticed for a number of years in the growing of summer legumes in the greenhouse in the winter, especially soybeans, that nodules do not form satisfactorily. To explain this condition the following preliminary experiments reported here were made.

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[1] Contribution from Soil Bacteriology and Plant Nutrition Investigations, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, D. C. Received for publication August 2, 1926.

[2] Associate Physiologist.

EXPERIMENT I

Two mixtures of soil were used, *viz.*, common greenhouse soil with a little manure and one part of this soil with three parts sand. The amount of soil necessary for the complete experiment was mixed at one time and placed in pots so as to have a similar soil for each planting. Five pots each of Tokio, Mammoth, and Wilson soybeans with six seeds to a pot were planted in each soil on the first of each month for practically a year. The beans were allowed to grow for two months. While no especial effort was made to keep the temperatures constant, the monthly averages varied but little from the general average of 20°C. from September to April, inclusive. In July and August the average temperatures were 29°C. and 30°C., respectively.

Examinations for nodules were made by dumping the pots, removing the plants, and washing the roots to eliminate the dirt. Nodules were then counted and notes made on the green weight, maximum and minimum heights, condition, and stage of growth of the plants. These plants were dried at a low temperature, about 60°C., and the dry weight determined before grinding for analysis. The results of this experiment are given in Table 1.

It is evident from Table 1 that numbers of nodules are higher in the longer-day months, the minimum number occurring in the months when the days are shortest. It is also evident that dry weight follows the same trend. The reverse is true of the percentage of nitrogen in the whole plant, although a calculation of the total nitrogen will show that the greatest amount of nitrogen was present when the plants were grown under the influence of the longer days. It is evident, also, that, in spite of no nodules or very few, the plants grown during the short days of the year took up relatively large quantities of nitrogen from the soil.

The lack of nodules on soybean plants is taken as an indication that due to a lack of light the carbohydrate production of the plant was insufficient or only sufficient for the immediate needs of the plant and that none of it could be spared for the activities of the legume organisms. Therefore symbiosis, as it is ordinarily understood, did not take place to any extent. Whether the organisms penetrated the root hairs and there died or remained inactive, or whether they would not or were not allowed to penetrate the roots is for further detailed work to endeavor to determine.

EXPERIMENT II

In this case Tokio soybeans were planted May 8, 1926, in greenhouse soil with which had been mixed before potting about 5% ground

TABLE I.—*Influence of planting time on growth, nodule formation, and nitrogen fixation by soybeans.*

	Soil									Sand								
	Mammoth			Tokio			Wilson			Mammoth			Tokio			Wilson		
Period of growth	Nodules[a]	Dry weight[b]	Nitrogen[c]	Nodules[a]	Dry weight[b]	Nitrogen[c]	Nodules[a]	Dry weight[b]	Nitrogen[c]	Nodules[a]	Dry weight[b]	Nitrogen[c]	Nodules[a]	Dry weight[b]	Nitrogen[c]	Nodules[a]	Dry weight[b]	Nitrogen
	No.	*Grams*	%	*No.*	*Grams*	%	*No.*	*Grams*	%	*No.*	*Grams*	%	*No.*	*Grams*	%	*No.*	*Grams*	%
7/1–9/2/24	17	26	3.34	29	40.8	2.92	10	30	3.14	15	30.4	2.82	22	38	2.36	9	26	3.12
8/1–10/1/24	20	38	3.32	28	36.5	3.12	6	24	3.60	28	27.6	3.06	28	40.5	2.48	5	16.6	3.44
9/1–11/1/24	14	20	2.86	13	16.6	2.84	6	31.3	2.98	12	19.0	2.90	13	18.4	2.42	3	10.7	3.12
10/1–12/1/24	11	20.7	3.34	7	20.2	2.86	7	11.8	3.82	4	13.8	2.78	1	15.7	2.82	1	11.9	3.28
11/1/24–1/2/25	2	13.3	4.12	1	10.9	2.62	1	6.6	4.60	1	7.5	3.90	1	9.5	3.88	1	15	4.52
12/1/24–2/2/25	1	6.7	4.36	0	8.0	4.86	0	6.5	5.32	1	3.1	5.70	1	6.5	5.70	0	3.1	7.50
1/2–3/2/25	8	12.5	4.68	7	10.4	5.48	5	10.3	5.16	1	8.6	5.40	1	8.6	5.78	1	6.9	5.40
2/2–4/1/25	19	29.2	3.62	21	26.6	3.46	12	20.4	4.02	3	18.4	3.22	4	17.7	3.10	3	11.2	3.34
3/2–5/1/25	29	34.7	3.46	40	47.2	2.82	17	32.7	3.16	33	23.3	3.20	27	22.6	2.76	16	20.6	2.66
4/1–6/1/25	38	102.0	2.76	44	71.3	2.62	22	83.3	2.66	10	96.0	2.32	4	333	1.88	11	55.0	2.64
5/1–7/1/25	20	59.0	2.58	35	97.5	2.32	19	96.0	2.40	20	72.0	2.42	33	136	2.58	16	115.0	2.80
6/1–8/1/25	16	89.5	2.20	22	100.0	2.22	21	141.0	2.56	23	136.0	2.18	30	118.0	2.54	17	82.0	2.70

[a] Average number per plant.

[b] Of 25 plants.

[c] Analytical work by Klare S. Markley.

limestone and a liberal amount of artificially prepared culture of soybean nodule bacteria. After 14 days the cotyledons were clipped from half of the plants. These same plants were further clipped five times at weekly periods leaving only one leaf on each plant. The results as they affected nodule formation are given in Table 2. At the close of the experiment the clipped plants were about 16 inches high and the unclipped 33 inches in height.

TABLE 2.—*Effect of leaf clipping on Tokio soybean.*

Treatment	Number of plants	Number of nodules	Size of nodules
Clipped	3	0	
Clipped	3	0	
Clipped	3	3	Small[a]
Clipped	1	0	
Unclipped	2	125	Medium[b]
Unclipped	3	50	Medium[b]
Unclipped	3	110	Medium[b]
Unclipped	3	74	Medium[b]

[a] About 1 mm. in diameter.
[b] About 3 mm. in diameter.

It will be noted that nodules are practically non-existent on the roots of the clipped plants, while on the normal plants nodules run as high as 62 per plant and average over 30 per plant. This experiment seems to be confirmatory of the results obtained in Experiment I. Here has been eliminated most of one of the carbohydrate-forming elements, chlorophyll, with light and carbon dioxide in liberal supply, whereas in Experiment I the light was limited at certain times during the work.

OBSERVATION ON CARBON DIOXIDE

In the 32-ounce glass bottles which are employed in this laboratory for the testing of legume cultures[3] under sterile conditions, it has been noticed on soybeans and other legumes that nodules form only sparingly and become visible very slowly, usually only after two months. Under field and pot conditions with favorable light and temperature, they usually occur in about 15 days. In these bottles, although the nodule-forming organisms are present in great quantity, only a few nodules are produced and some of the plants often are without nodules. In this case carbon dioxide is limited and light, to some extent. There is a possibility that each factor contributes to the condition noted, but presumably the plants which are more capable of utilizing the limited quantity of carbon dioxide present and slowly diffusing through the cotton plug are the ones on which nodules are found.

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[3] LEONARD, L. T. Nodule production kinship between the soybean and the cowpea. *In* Soil Sci., 15:279, 1923.

To remedy this lack of carbon dioxide, dextrose was incorporated into the medium and at the time the seed were inoculated gas-producing organisms, *B. aerogenes*, *B. coli*, and *B. cloacae*, were introduced in separate series of bottles. Dextrose had a detrimental influence on the roots, but the nodules formed were nearly twice as large as those commonly produced. Whether this will be a practical means of introducing carbon dioxide into test bottles further experiments are now in progress to determine.

CONCLUSION

This preliminary work indicates that nodule formation on certain varieties of soybeans is intimately connected with the carbohydrate-forming function of the plant, so much so that nodules will form sparingly or not at all when insufficient light, carbon dioxide, or chlorophyll excessively diminishes the capacity of the plant to produce the proper carbohydrate

APPLICATION OF THE ROBINSON METHOD TO THE DETERMINATION OF CLAY[1]

E. B. ENGLE AND D. R. YODER[2]

INTRODUCTION

Robinson (4)[3] and Jennings, Thomas, and Gardner (3) contemporaneously have proposed a new method for the determination of soil separates. The Robinson method seemed so simple, reliable, rapid, and well adapted to laboratory studies[4] that it was immediately investigated as a method for the determination of clay (particles (.005 mm. diameter) in the Soils Laboratory at the University of Nebraska. The centrifugal method for the determination of clay previously in use has been practically abandoned.

The purpose of this paper is to give the technic of the Robinson method as developed and standardized in this laboratory, and to show the comparison between it and the centrifugal method.

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[1] Published with the approval of the Director as Paper No. 26, Journal Series, Nebraska Agricultural Experiment Station, Lincoln, Nebr. Received for publication August 4, 1926.

[2] Instructor in Soils and Fellow, National Lime Association, respectively, Department of Agronomy, University of Nebraska, Lincoln, Nebr. The junior author wishes to express his appreciation to the National Lime Association for the time allowed him for this study

[3] Reference by number is to "Literature Cited," p. 1025.

[4] An illustration of its application is to be found in the work of Russel and Engle on soil horizons in the Great Plains. *In* Bul. 6, Proc. Amer. Soil Survey Assoc. 1924.

TECHNIC OF THE METHOD

The special equipment required in this method is indicated in Fig. 1. A series of 8 to 12 cylinders is advantageous. The cylinder (A) has an inside diameter of 77 mm. and is 384 mm. high. A 1,500 cc. mark on the cylinder should not be less than 30 mm. from the top. It is convenient to have the several cylinders arranged according to their ascending weights and to have one lead counterpoise for the first cylinder and additional additive lead weights to counterpoise each of the other cylinders. Soil equivalent to 15 grams water-free weight is thoroughly deflocculated,[5] using ammonia as a deflocculator, and transferred to the cylinder. Each cylinder is counterpoised in turn, on a platform scale, 1,515 grams of weights are added, and distilled water poured into the cylinder to balance. The temperature of the water should be the same as that of the laboratory and should not be allowed to change appreciably during the course of the determination. The soil in the first cylinder of the series is brought into suspension by means of a stirrer (D) consisting of a perforated metal disc fastened to a metal rod. About two minutes is allowed for stirring, stirring being stopped on the minute. A paraffined wooden block (B) is placed on the cylinder and the pipette (C) immediately adjusted. The pipette bears a mark 10 cm. from the

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[5] While carrying on this study, considerable difficulty was experienced in securing complete deflocculation of the soil by the shaking method and it was necessary to spend some time in finding a satisfactory method for deflocculation. The method finally adopted, which will hereafter be referred to as the trituration method, is described below. Data showing results obtained by the trituration method and the comparison between this method and other methods of deflocculation will be presented in a later article.

The method of deflocculation is as follows: A sample of soil equivalent to 15 grams of water-free weight is transferred to a 100 cc. centrifuging tube. About 25 cc. of distilled water and 1 cc. of strong ammonia are added and the soil triturated thoroughly with a glass stirring rod. Any soil adhering to the stirring rod is washed free with a jet of water from a pressure bottle and the next sample triturated. When all the soils have been triturated, the tubes are filled with the aid of a strong jet of water so as to put the soil into suspension, and centrifuged just long enough to insure that all undeflocculated material is thrown down. The time of centrifuging will vary of course with the speed and type of the centrifuge. The centrifuge used in this laboratory is one of the usual type built by the International Equipment Company for mechanical analysis of soils. After centrifuging, the suspension is poured into the sedimentation cylinders described below. The soils are again triturated as before, adding 2 to 3 drops of ammonia, instead of 1 cc., to each tube. When the soil no longer adheres to the glass stirring rod, trituration is carried on without the addition of water and with a rubber capped stirring rod about 10 mm. in diameter. A rubber bulb such as used on a medicine dropper makes a very convenient cap for the stirring rod. Usually about 12 triturations are sufficient to deflocculate the heavier soils.

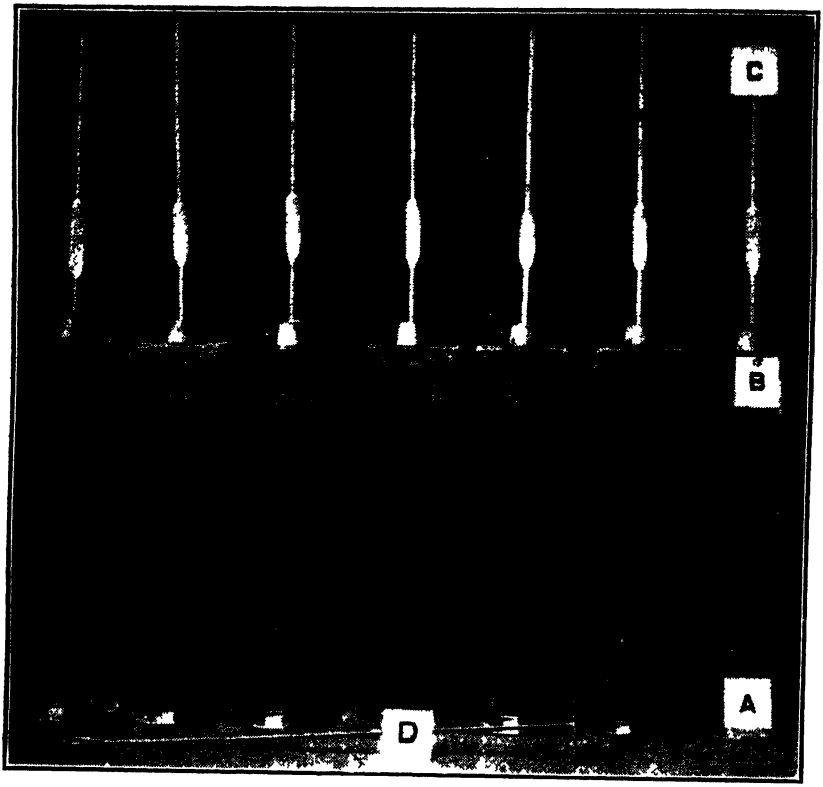

FIG. 1.—Apparatus used in the Robinson method for clay determination.

tip and is supported by a rubber stopper The pipette should be calibrated to deliver 15 grams of water, which is 1/100 of the volume of the soil suspension The pipette is introduced into the suspension as carefully as possible and slowly pushed down through the stopper until the 10 cm mark comes exactly to the level of the surface. It is convenient to stir the next suspension in the series so that it begins to settle exactly three to five minutes later than the preceding one, thus giving sufficient time for the withdrawal of samples at the end of the sedimentation period The period of sedimentation, which varies with the temperature of the water, is calculated (Table 1) and each cylinder is allowed to stand without disturbance for that interval. At the end of the period of settling the pipette is slowly and carefully filled by suction with the mouth and the contents are drained into a weighing bottle previously oven dried and weighed to the fourth decimal. The liquid in the weighing bottle is evaporated and the clay dried in an oven at 110°C. and then reweighed. As the weight of clay in the bottle is 1/100 of the clay in the original sample of 15 grams, the percentage is readily calculated. If sand and silt are desired, the suspension is siphoned off and the residue transferred to a beaker. The sand is determined directly in the usual manner and the silt determined by difference.

TABLE 1.—*Coefficient of viscosity of water at temperatures from 15° to 30°C. and time for the sedimentation of particles 0.005 mm. in diameter.*

Temperature, C.	Coefficient of viscosity of water	Time in minutes to settle 10 cm
15°	0.01140	84.6
16°	0.01110	82.5
17°	0.01082	80.3
18°	0.01055	78.3
19°	0.01029	76.3
20°	0.01005	74.6
21°	0.00980	72.7
22°	0.00958	71.1
23°	0.00936	69.4
24°	0.00915	67.9
25°	0.00894	66.3
26°	0.00875	64.9
27°	0.00856	63.5
28°	0.00838	62.2
29°	0.00820	60.8
30°	0.00801	59.4

CALCULATION OF TIME FOR SEDIMENTATION

The Stokes formula can be changed to make the calculation for time of sedimentation at various temperatures very simple. The original formula[6], $V = \frac{2\,gr^2\,(s-s_1)}{9\,n_t}$, becomes $V = \frac{2g\,(s-s_1)}{9\,n_t}\,\frac{d^2}{20^2} \times 60$, when the diameter (d) of the particle is expressed in millimeters and the velocity of fall is expressed in centimeters per minute. From the latter equation, two simple formulae may be derived, when g, s, and s_1 are assigned their approximate values, as follows:

$$\text{(a)}\quad T = 7421\,n_t$$

$$\text{(b)}\quad T = \frac{0.1855\,n_t}{d^2}$$

[6] V = velocity of fall in cm/sec.
g = gravity (= 980)
r = radius of particles in cm.
s = density of suspended material (= 2.65)
s_1 = density of suspending medium (= 1.0)
n_t = coefficient of viscosity of suspending medium at sedimentation temperature.

The first formula may be used for calculating the time (T), required for particles to fall 10 cm. when the maximum diameter is 0.005 cm. The second formula may be used when some other than the routine clay fraction is being determined.

Table 1 gives the coefficient of viscosity of water (2, p 451) at temperatures ranging from 15° to 30°C., and also the calculated time of sedimentation for clay particles of 0.005 mm. maximum diameter.

EFFECT OF TEMPERATURE

No difference is found in the clay content of soils when working at different temperatures, as is shown by the data in Table 2. Unless a constant temperature room is available it is possibly easier to make the determination at whatever temperature can most easily be kept constant rather than attempt to adjust the temperature of the laboratory to some definite degree. It is important that the temperature be kept constant within a degree. This can be done ordinarily by adjusting the water to room temperature and paying close attention to the heating and ventilating of the room.

TABLE 2.—*The percentage of clay in two soils determined at various temperatures.*

Temperature, C.	Soil No. 2717	Soil No. 1011
15°	44.5	8.8
	44.2	8.9
21°	44.0	8.9
	—	8.9
36°	44.0	8.7
	43.9	8.7

REMOVING THE SAMPLE

Robinson has shown that the sample can be removed from any depth, but where the pipette is placed in the cylinder during the period of sedimentation the 10 cm. depth seems most desirable. Robinson does not place the pipette into the suspension until ready to withdraw the sample, and while inserting the pipette keeps the upper end closed until it is immersed to the proper depth below the surface. While this method of procedure is the only sound one in theory, there is always a danger of roiling the suspension while inserting the pipette and thus introducing error. When the pipette is placed in the suspension at the beginning of the sedimentation period the error due to roiling is avoided. However, another error is introduced in that the stem of the pipette is filled to the 10 cm. mark with a suspension of lower average concentration than exists at the point from which the sample is taken. In other words, one does not remove exactly 15 cc. of the solution of the concentration sought. With pipettes having stems of small bore, the error which arises from having the pipette in the cylinder during the sedimentation period is practically negligible, as shown in Table 3.

TABLE 3.—*The clay content of two soil suspensions determined by the usual method of inserting the pipette at the beginning of sedimentation, as compared with the method of introducing the pipette at the end of the sedimentation period.*

	Pipette in cylinder during sedimentation		Pipette placed in cylinder at time of sampling	
	Suspension A, % clay	Suspension B, % clay	Suspension A, % clay	Suspension B, % clay
	47.9	23.3	48.3	22.8
	46.9	23.3	48.5	23.3
	48.0	23.0	48.1	23.1
	47.9	24.0	48.4	23.2
Ave.	47.7	23.5	48.3	23.1

EFFECT OF SMALL VARIATIONS IN DEPTH OF SAMPLING

The withdrawal of 15 cc. of suspension causes a fall in the level of about 3 mm. when cylinders of 77 mm. in diameter are used. Robinson (4, p 311) has discussed the question of the area from which the liquid is removed and has given data to show that an error of a few millimeters in the depth of sampling involves only a negligible error in the final results.

Data to show the effect of small differences in the depth of sampling are given in Table 4. Homogeneous suspensions of three different soils were used and the pipettes were introduced to depths of 9.5, 10.0, and 10.5 cm. A variation of 0.5 cm. either side of the 10 cm. depth affected the clay content to a negligible degree. In some additional studies on a considerable number of soils varying in texture from a medium sand to a heavy clay, it was found that 70 to 80% of the clay fraction consisted of particles less than 0.002 mm. in diameter. This explains why small variations in depth of sampling were not a source of error.

TABLE 4.—*Effect of small variations in depth of sampling on the percentage of clay found in three soil suspensions.*

	Depth of sampling		
	9.5 cm.	10.0 cm.	10.5 cm.
		Suspension C	
	50.8	50.6	50.8
	49.9	50.6	51.0
Average	50.4	50.6	50.9
		Suspension D	
	23.3	24.1	23.3
	22.3	23.3	23.0
Average	22.8	23.7	23.2
		Suspension E	
	9.5	9.9	9.7
	9.5	9.7	9.7
Average	9.5	9.8	9.7

AGREEMENT OF REPLICATED DETERMINATIONS AND DETERMINATIONS MADE BY TWO INDIVIDUALS WORKING ON THE SAME SOILS

One point of special importance in a method for mechanical analysis is the agreement in replicated determinations and in determinations made by two individuals working with the same soils. Data are presented in Table 5 to show the agreement between replicated determinations on two soils and three homogeneous suspensions. The percentage of clay in the two soils shows the agreement with respect to the complete method of analysis, and the percentages of clay in the suspensions show the agreement with respect only to the removal of the clay. In Table 6 data are given showing the percentage of clay found by two individuals working with the same soils.

TABLE 5. *Replicated determinations by the Robinson method.*

	Soil		Suspension		
	2717, % clay	2986, % clay	F, % clay	G, % clay	H, % clay
	44.5	40.6	49.9	22.9	9.2
	44.2	39.6	50.1	22.9	9.1
	43.8	39.9	49.4	22.8	9.3
	43.4	39.7	48.9	22.9	9.3
	44.0	40.3	49.6	23.7	9.0
	44.0	39.9	49.0	23.0	9.2
	43.9	40.3	50.0	23.6	8.7
	43.7	40.1	49.0	24.0	8.9
Ave.	43.9	40.0	49.5	23.2	9.1

It is generally recognized that with the centrifugal method considerable variation is found in the percentage of separates obtained by workers in different laboratories when working with the same soil. This it seems is explained by the fact that a considerable part of the technic of the method is dependent upon the judgment of the analyst. The speed of the centrifuge, the period of centrifuging, the care used in pouring off, and one's judgment as to when the separation of clay is complete are all factors in the centrifugal method which lead to serious variations in results. The essential features of the Robinson method may be standardized and when such is done very little is left to the judgment of the analyst. The data in Tables 5 and 6 indicate that the Robinson method will give results that meet the requirements of practically all physical investigations in soils.

AGREEMENT OF THE ROBINSON AND CENTRIFUGAL METHODS

Robinson has shown that his method (4, p 318) compares very well with the English method of mechanical analysis. It seemed desirable, however, to make a comparison between the Robinson and centrifugal methods as carried out in this laboratory. The analysis by the latter

TABLE 6.—*Percentage clay found in the same soils by two individuals, A and B.*

Soil No.	Percentage clay		Variation
	A	B	%
1352	69.9	69.9	0.0
1010	48.3	50.4	2.1
2717	45.1	44.4	0.7
2531	44.7	44.8	0.1
2530	43.3	44.5	1.2
2718	42.9	42.1	0.8
2532	41.6	41.5	0.1
2539	38.9	39.3	0.4
2716	37.7	37.7	0.0
2533	37.6	37.5	0.1
2719	36.5	37.6	1.1
2534	35.2	36.5	1.3
2528	34.8	35.2	0.4
2720	34.0	34 5	0.5
2715	33.3	35.8	2.5
2721	31.7	31.7	0.0
2543	28.1	28.7	0.6
2542	27.7	27.4	0.3
2544	27.6	26.3	1.3
Pratt	27.2	26.1	1.1
2545	25.1	25.2	0.1
2547	20.1	21.1	1.0
2546	20.0	21.0	1.0
2548	19.7	20.2	0.5
1018	11.2	10.9	0.3
1011	8.7	8.9	0.2
1017	4.3	4.0	0.3
2437	4.0	4.2	0.2
Average	— -	- —	0.65

method was made in accordance with the Bureau of Soils method (1), except in the deflocculation of the soils.

In the separation of clay by the centrifugal method, deflocculation was obtained by trituration as in the Robinson method. The speed of the centrifuge was 1,300 r.p.m. and the minimum time of centrifuging was 60 seconds. The samples were considered to be free of clay when the lines of the fingers were distinctly visible through the suspension. The amount of clay was determined by difference after drying and weighing the combined sand and silt from which the clay had been separated.

The percentage of clay obtained by the two methods is given in Table 7. In all but two sandy soils, the percentage of clay obtained by the centrifugal method is lower than that obtained by the Robinson method. Under the microscope, the clay suspension removed in the Robinson method shows occasional flat and defaced slow-settling particles larger than clay. These one would call silt in the centrifuge method and would avoid decanting by prolonging the centrifuging period. These particles would increase the apparent clay content by the Robinson method. On the other hand, through attempting to save these particles, clay will be incompletely removed by the centrifuge method. The difference in the two methods seems to be due in the main to the fallacy of one's judgment of what is and what is not clay under the microscope.

TABLE 7.—*Comparison of the Robinson and centrifugal method for the determination of clay.*

Soil No.	Percentage clay		Difference	$\frac{\text{Cen.}}{\text{Rob.}}$[b]
	Robinson method	Centrifugal method	%	
1352	69.9	62.1	7.8	0.88
1010	50.4	46.7	3.7	0.92
H[a]	48.0	46.1	1.9	0.96
D	38.9	30.3	8.6	0.77
2533	37.5	34.5	3.0	0.92
2528	35.2	31.0	4.2	0.88
C	33.0	29.2	3.8	0.88
2545	25.2	23.9	1.3	0.94
G	24.4	22.9	1.5	0.93
B	23.1	19.6	3.5	0.84
2548	20.2	19.9	0.3	0.98
F	14.5	12.3	2.2	0.84
1011	8.9	6.9	2.0	0.77
A	4.4	2.6	1.8	0.59
1017	4.0	4.4	—0.4	1.10
E	3.8	4.1	—0.3	1.07
Average	—	—	2.9	0.89

[a] Soils designated by letters were analyzed by students in the course in Soil Physics.

[b] $\frac{\text{Percentage clay centrifugal method}}{\text{Percentage clay Robinson method}}$.

CONCLUSIONS

The Robinson method for the determination of clay is simple and accurate, more subject to standardization than the centrifugal method, and will lead to more comparable results in the hands of different investigators. It is more rapid than the centrifugal method and will allow more extensive use of clay determinations in soil studies and in soil survey control work.

The accuracy of the results obtained by the Robinson method is dependent more upon the completeness of deflocculation of the soil sample than upon any other feature of technic. When the method of deflocculation has been standardized, the Robinson method for clay determination will be one of highest merit. At present the method described cannot be recommended for alkali and highly calcareous soils, due to their tendency to reflocculate on standing.

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SOME DEVICES AND METHODS USED IN TEACHING SOILS[1]

A. B. Beaumont[2]

Within the past few years some devices and methods have been used in the teaching of courses in soils at the Massachusetts Agricultural College with sufficient success to warrant reporting. They affect the following topics of instruction: (1) Soil formation and classification, (2) tillage, and (3) the field problem.

SOIL FORMATION AND CLASSIFICATION

A "sand" table was made by mounting on a sturdy table a shallow box. In this have been demonstrated soil differences as influenced by method of formation, parent material, texture, color, etc. Drumlins, eskers, terraces, alluvium, muck soils, and peat bogs can be shown. (See Fig. 1.) With it, differences in soil series and types due to topography, color, and other factors can be vividly illustrated. In short, with this device the ingenious teacher can illustrate nearly all the agencies and factors affecting soil formation and classification. The student's imagination, however, must be brought into play.

Such a device should be considered a supplement to rather than a substitute for field studies in soil formation and classification. True, it is artificial in its make-up, but that has advantages. Points which may have no counterpart in the natural environment may be brought out by means of it, and on account of the reduced scale employed, direct comparisons may be made which may be difficult to see in the field. The "sand" table method has been used in teaching military tactics, but so far as the writer knows has not been used extensively, if at all, in the teaching of soils.

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[1] Contribution from the Department of Agronomy, Massachusetts Agricultural College, Amherst, Mass. Received for publication August 6, 1926.

[2] Professor of Soils.

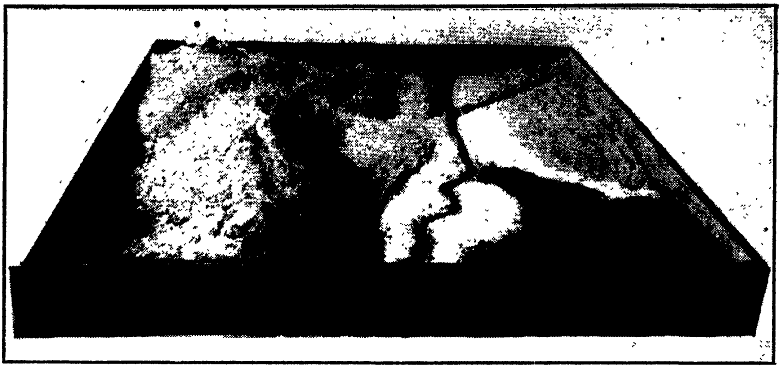
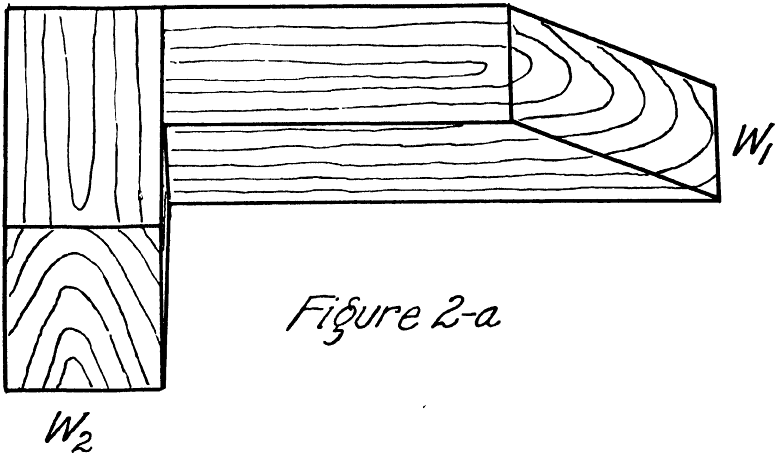
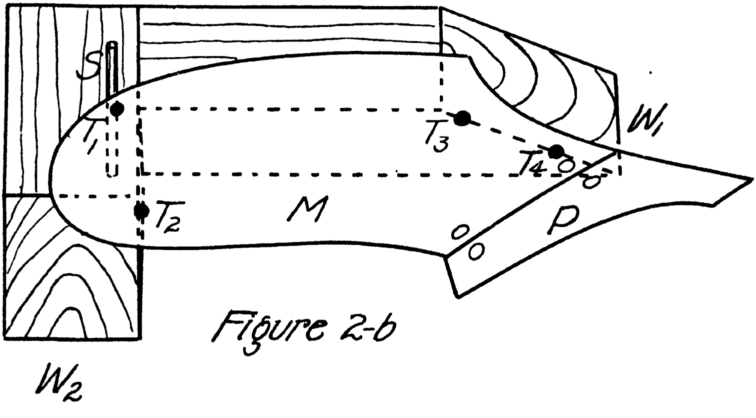


FIG. 1.—"Sand" box containing soil and topographic model used in introductory courses in soils.





In connection with the subject of soil classification it may be worth mentioning in passing that our soil survey maps are mounted on heavy Beaver (wall) board for student use in the laboratory. In this way the maps are more easily handled and are more durable. A coating of shellac increases the durability.

TILLAGE

The development and action of the modern plow bottom has been taught with the aid of two wooden wedges and a piece of cardboard cut in the shape of a plowshare and moldboard. (See Figs. 2-a and 2-b.) The wedge (W_1) was made from a piece of dressed 2 x 4 scantling beveled on one side as shown. This wedge represents one of the first developments of the plow bottom and a form still used in principle by primitive farmers. By placing another wedge (W_2) of the same size as the first (W_1) at a right angle to W_1, as shown in Fig. 2-a, the foundation of the modern plowshare is laid. By connecting the beveled edges of the wedges with a narrow strip of cardboard the principle of the plowshare, a modified double-wedge, is established. At this point attention should be called to the fact that two wedges as shown in Fig 2-a were not and could not be used as a plow but that longitudinal and cross sections of a modern plowshare will show its double-wedge nature. It is this modified double-wedge that gives the plow bottom its efficiency as a shearing and lifting implement, and this plus a moldboard makes it a turning and pulverizing implement.

A flexible cardboard moldboard and plowshare fastened to the wedges and the wooden supporting pin S by thumb-tacks T_1, T_2, T_3, and T_4 completes the model. The shape and curvature of the moldboard may be modified at will to demonstrate different types of plows and their relation to turning and pulverizing. By building up this synthetic plow bottom step by step before the student the evolution and the shearing, turning, and pulverizing actions of the modern plow bottom can be strikingly illustrated.

The relation of the ratio of width to thickness of furrow slice to the position the furrow slice takes when turned has been demonstrated by means of wooden blocks cut from a dressed 2 x 4 scantling. Blocks with a wide ratio (say 3:1) permit a very small lap, as L_1 in Fig. 3; those with a narrow ratio (say 1.5:1) permit a much wider lap, as L_4 in Fig. 4. In practice the furrow slice as shown in Fig. 3 usually sags and crumbles sufficiently to cause it to fall flat, and we have the "flat furrow" type of plowing, while with the narrow ratio we can more easily get the "lap furrow."

This relation can further be demonstrated mathematically by comparing the right triangles $A_1B_1C_1$ and $A_4B_4C_4$. As the angle A becomes smaller the sides AC and AB approach each other in length and the lap L becomes smaller.

THE FIELD PROBLEM

This covers a method that was first tried here in 1919 and first reported on 1922.[3] Details of the method were given then and will not be repeated here They have not been materially altered. Briefly, the field problem in soils involves a modification of the project system of teaching as developed in the secondary schools. Through its use the student is led to see the relation of soil science to the practical problems of soil management. The method involves a problem which is about as real as can be made under teaching conditions and serves as a sort of climax for summing up the student's knowledge of soils and his ability to apply it. It has been used with success in all our soils courses. It has been developed most fully in those courses which permit considerable time for laboratory or field work. Rightly used it is an effective method in the teaching of soils.

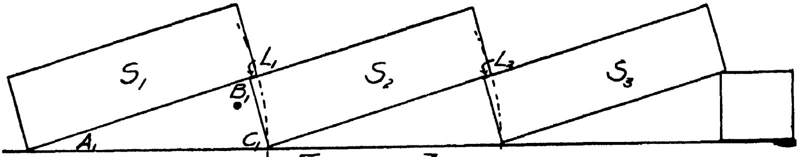


Figure 3

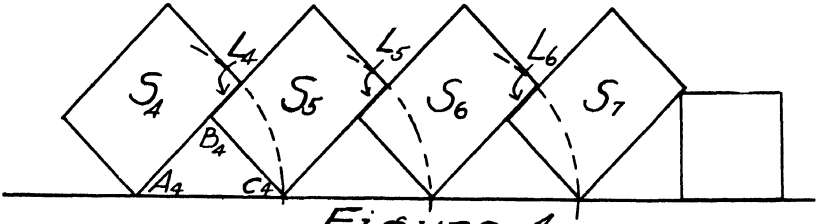


Figure 4

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MOISTURE CONTENT OF CORN IN RELATION TO RELATIVE HUMIDITY AND TEMPERATURE OF THE ATMOSPHERE[1]

H. W. ALBERTS[2]

Moisture in shelled corn or corn on the ear has a tendency to be in equilibrium with that of the air surrounding it. Seed corn is often stored in the open air throughout the winter and is thus subjected to different atmospheric relative humidities and temperatures which affect the moisture content of the grain. In the following investigation an attempt was made to determine the percentage of moisture that may be expected in corn at various temperatures and relative humidities.

MATERIALS AND METHODS

Reid Yellow Dent corn grown in the fields of the Illinois Agricultural Experiment Station was used. It was harvested in October, 1924, and stored in a room at a temperature of approximately 22°C. until the following December. During this time the moisture content had been reduced to 11.0% (total weight basis). Samples of the shelled corn weighing 110 grams were placed in wire baskets, which were suspended for four weeks from hooks sealed to covers of 2-quart fruit jars. Each jar contained 250 cc. of sulfuric acid of such concentrations that the resulting relative humidities of the atmosphere above the solutions in the sealed jars ranged between approximately 0% to 100%. The necessary concentrations to be used were calculated from Stevens (6)[3], and the amounts of acid and water for each jar were calculated from Atack (1). The calculation of adjustment of specific gravities to 0°C. was made from Thorpe (7) and that of the percentage of acid from Olson (5). The results obtained correspond quite closely to those obtained by Coleman and Fellows (3) who used the method described by Wilson (8).

At the close of the experiment a specific gravity test of the solutions and a moisture test of the corn were made. The specific gravity of the solutions was obtained from hydrometer readings and the moisture content of corn was obtained by weighing approximately 20 grams of corn and drying it for ten days at 104°C. Percentage loss in weight was based upon the original weight of the sample.

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[1] Contribution from the Departments of Botany and Agronomy, University of Illinois. The work upon which this paper is based was done under the direction of Dr. Charles F. Hottes and Dr. W. L. Burlison to whom the writer is indebted for helpful suggestions and constructive criticisms. Received for publication June 26, 1926.

[2] Formerly Instructor in Agronomy, University of Wisconsin, Madison, Wis.

[3] Reference by number is to "Literature Cited," p. 1034.

EXPERIMENTAL DATA

Jars as described above were placed in cases and constant temperatures of 10°, 20°, and 30°C., respectively, were maintained throughout the experiment. The temperature of approximately 0°C. reported below fluctuated widely since the outdoor temperature was depended upon and no effort was made to keep the temperature of the contents of these jars constant.

The water in the jars in which a nearly saturated atmosphere was maintained was found at the close of the experiment, to have a distinctly higher specific gravity than pure distilled water and in the jar maintained at 30°C. the air had the odor first of alcohol and later of acetic acid.

TABLE 1.—*Specific gravity of acid, relative humidity of the atmosphere, and moisture content of corn in jars containing water and acid solutions at low temperatures.*

Observed specific gravity at 2°C.	Calculated specific gravity for 0°C.	Sulfuric acid in solution	Approximate relative humidity	Moisture in corn
		%	%	%
1.004 (water)	——	0	100	23.1
1.155	1.157	20.7	87.9	19.0
1.215	1.217	28.3	77.3	16.6
1.301	1.303	38.3	57.7	13.2
1.406	1.408	49.6	38.4	10.9
1.485	1.487	57.3	20.5	9.0
1.579	1.581	65.8	9.7	8.4
1.847	1.849	92.8	——	8.7

It was found as indicated in Table 1 that the moisture content of corn ranged from 8.4% over high concentrations of acid to 23.1% over water. It will be noted that the moisture content at 9.7% relative humidity was 8.4%, while the moisture content of corn over concentrated sulfuric acid was 8.7%. This difference is so slight that it may have been due to variations in manipulations such as weighing the samples.

Where the temperature was kept under control and maintained at 10°C. the moisture content of corn between the relative humidities of 10% and 90% was similar to that in corn kept at a lower temperature. In this lot the moisture content ranged from 5.7% to 22.7%, as shown in Table 2.

In the lots of corn where the temperature was maintained at 20°C., as shown in Table 3, the moisture content ranged from 7.2% over the acid of high concentration to 24.7% over water. Where the relative humidity was above 90%, the moisture content of corn was higher than in the corn at the corresponding relative humidity at 10°C.

TABLE 2.—*Specific gravity of acid, relative humidity of the atmosphere, and moisture content of corn in jars at 10°C.*

Observed specific gravity at 10°C.	Calculated specific gravity for 0°C.	Sulfuric acid in solution	Approximate relative humidity	Moisture in corn
		%	%	%
1.005 (water)	——	0	100	22.7
1.151	1.157	20.7	87.9	18.0
1.211	1.218	28.3	77.1	15.4
1.299	1.306	38.7	57.1	12.2
1.406	1.414	50.3	34.0	9.4
1.473	1.481	56.8	21.3	7.9
1.573	1.581	65.8	9.7	6.4
1.838	1.847	92.8	——	5.7

TABLE 3.—*Specific gravity of acid, relative humidity of the atmosphere, and moisture content of corn in jars at 20°C.*

Observed specific gravity at 20°C.	Calculated specific gravity for 0°C.	Sulfuric acid in solution	Approximate relative humidity	Moisture in corn
		%	%	%
1.002 (water)	——	0	100	24.7
1.157	1.169	22.1	84.2	18.8
1.205	1.219	28.3	76.9	16.4
1.295	1.308	39.1	56.6	12.9
1.397	1.413	50.2	35.3	9.7
1.472	1.488	57.5	20.4	8.3
1.557	1.573	65.2	10.3	8.0
1.827	1.847	92.5	——	7.2

When the temperature was maintained at 30°C., the moisture content of corn at relative humidities from 10% to 90% was approximately the same as that of the corn kept at lower temperatures, as shown in Table 4.

TABLE 4.—*Specific gravity of acid, relative humidity of the atmosphere, and moisture content of corn in jars at 30°C.*

Observed specific gravity at 30°C.	Calculated specific gravity for 0°C.	Sulfuric acid in solution	Approximate relative humidity	Moisture in corn
		%	%	%
1.000 (water)	——	0	100	30.1
1.143	1.161	21.0	87.2	18.4
1.200	1.220	28.5	76.7	153
1.288	1.308	39.1	56.3	12.2
1.394	1.417	50.6	33.0	9.6
1.469	1.492	57.9	19.9	7.9
1.557	1.581	65.7	9.7	6.2
1.823	1.852	90.6	——	4.7

DISCUSSION

A careful examination of the results above indicates that the moisture in the corn was practically independent of temperature and varied only with relative humidity, except when the latter was ex-

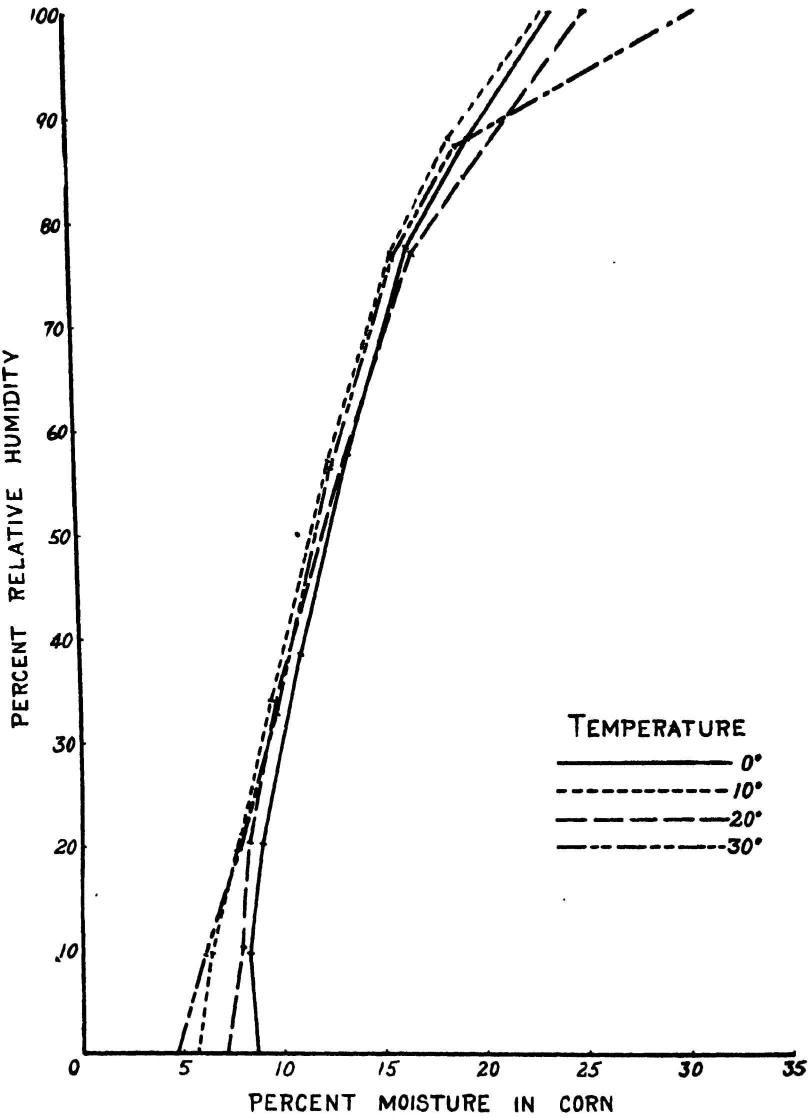

FIG. 1.—Percentage moisture in corn at different relative humidities and temperatures.

tremely low or extremely high. Below 10% and above 90% relative humidity the moisture content of corn varied also with temperature, as shown in Fig. 1. When the relative humidity was approximately 100%, the moisture content was greatest at the highest temperature, and when the relative humidity approached 0%, the moisture content of corn was greatest at the lowest temperature.

In order to give a clearer understanding of the relation of the relative humidity to the moisture content of corn, Table 5 was compiled. This table shows the approximate moisture content of corn at 10% relative humidity and for multiples of 10% up to and including 90%. The figures shown in the table can serve only as a general guide since many other factors, such as varietal differences and age of seed as reported by Bailey (2), affect moisture content of corn.

TABLE 5.—*Approximate moisture content of corn at different relative humidities.*

Relative humidity	Moisture in corn
%	%
10	7
20	8
30	9
40	10
50	11½
60	13
70	15
80	17
90	20

It is evident that the relation of relative humidity to the hygroscopic moisture in corn has a direct bearing upon heating and ventilation of seed corn storage houses. A low relative humidity produces a low moisture content in corn. Heating the air increases its moisture holding capacity. Table 6 shows the weight of a cubic foot of saturated vapor at 32°F., 42°F., 52°F., 62°F., and 72°F., respectively. These figures were obtained from Marvin (4).

TABLE 6.— *Weight per cubic foot of water vapor (100% saturation) at different temperatures.*

Temperature, degrees F.	Weight of cubic foot of vapor, grains
32	2.11
42	3.06
52	4.37
62	6.14
72	8.51

From Table 6 it may be concluded that when the temperature of air is raised from 32°F. to 52°F., its moisture holding capacity is approximately doubled; if raised to 62°F., its moisture holding capacity is increased three times; and if raised to 72°F., its moisture holding capacity is increased to four times that of air at 32°F. Between the freezing point of water (32°F.) and ordinary room temperature (72°F.), a rise of 20°F. will double the moisture holding capacity of air. Thus, when seed corn storage houses are heated artificially on a cold winter day, the moisture holding capacity of the air is increased and moisture from corn is absorbed by the air until the moisture absorbing power of corn is in equilibrium with that of the air. To secure the maximum drying effect, this air, with its increased amount of moisture, should be replaced frequently by heated dry air.

SUMMARY

The moisture absorbing capacity of corn varied with the relative humidity.

The effect of temperature upon the moisture absorbing capacity of corn at relative humidities between 10% and 90% was negligible.

Above 90% relative humidity, the moisture content of corn was greatest at the highest temperature.

Below 10% relative humidity the moisture content of corn was greatest at the lowest temperature.

Since a rise in temperature increases the moisture absorbing capacity of the air, it is deemed advisable to apply artificial heat together with ventilation on cold winter days to maintain a low moisture content of corn in seed corn storage houses.

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THE RESPONSE TO LIMING AND FERTILIZATION OF THE RECLAIMED MUCK LANDS OF NORTH CAROLINA[1]

(Abstract)

L. G. WILLIS[2]

The muck and peat soils of eastern North Carolina have not maintained the fertility evident when drainage was first established. All types are extremely acid, but liming is only partly effective in overcoming the effect of soil acidity as the high concentration of lime required to bring the soil to neutrality results in a depression of potash assimilation. Heavy fertilization with potash is necessary to correct the depression in crop yield following the application of more than 2 tons of lime per acre. This lime-potash relation is most marked on soils low in mineral matter as the lime in these is less readily fixed as insoluble silicates.

With the surface soil adequately limed the acid subsoil is injurious to corn. Heavy liming and deep plowing have not served to remedy this condition.

Lime applied to the surface soil does not affect the reaction of the underlying soil to a depth of more than 1 inch.

Fertilization with nitrate of soda and potash has been beneficial, more so on the mucks low in mineral matter than on others. Acid phosphate is generally injurious or without effect.

Corn yields are better following soybeans or a green manure crop than after corn or fallow.

Shallow plowing and bedding has given better results than other cultural methods.

The outlook for the development of these tracts in truck or other intensive crops is not promising. If cultivation can be maintained it is probable that the soils will become more and more productive as the rate of decomposition is abated.

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WISE USE OF FERTILIZERS ON COTTON—THEIR EFFECT UPON YIELD AND MATURITY FOR DIFFERENT SOILS IN NORTH CAROLINA[1]

C. B. WILLIAMS[2]

Cotton has averaged in value during the past two years about 35 % of the total value of all the crops grown in North Carolina. There can be no doubt that the welfare of a larger number of the people of this state is vitally involved in the profitable production and handling of this crop than any other crop grown in the state. It is estimated that during 1924 at least $12,000,000 were expended by farmers of the state for fertilizers to use in bettering the production of this crop.

Notwithstanding the fact that North Carolina cotton growers are using commercial fertilizers as efficiently as farmers of any state of the cotton belt, it is believed there are great possibilities even yet in the improvement of the kinds of fertilizers to be bought and used for the production of this crop. No one conversant with the facts can question that there has been a gradual improvement in the better adjustment of the fertilizers used to meet the requirements of cotton grown on the soils of different sections of the state. For a number of years, North Carolina growers consistently have obtained larger average yields of lint per acre of cotton than has been secured on an average by the growers of other sections of the cotton belt. One of the biggest factors which has contributed to this condition has been the better knowledge and judgment which North Carolina farmers have exercised in the selection and use of the commercial fertilizers they have used. They have learned that the wise selection and use of these will pay well during a normal season and when the prices for the cotton are satisfactory. In 1924, they used them in North Carolina at the rate of 450 pounds per acre.

FACTORS DETERMINING THE EFFICIENCY AND VALUE IN THE USE OF FERTILIZERS

In order to have fertilizers serve most efficiently when used in the growth of this crop the following factors must be carefully looked after by the growers: (a) A suitable soil must be selected. It must be well prepared and the crop cultivated in the most effective way.

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[1] Paper read at the meeting of the Agronomy Section of the Association of Southern Agricultural Workers held at Atlanta, Ga., February 3–5, 1926. Received for publication September 10, 1926.

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(b) The method and time of application of the fertilizer are factors which will usually exert a tremendous influence on the efficiency with which the fertilizers act. (c) The kind and amount of fertilizers per acre, availability of the materials, and the proportioning of the plant-food constituents in the fertilizers to best fit them to the particular needs of the soil are highly essential.

In the case of the individual farmer, the more nearly he can secure a fertilizer mixture which meets the particular needs of his soil, the greater on an average, will be his returns. The type of soil and the condition in which this soil is in at the time are essential factors, too, which should be taken into consideration in settling upon best analyses of fertilizer mixtures to use.

EFFECT OF COMPOSITION OF FERTILIZERS UPON MATURITY

The data presented in Table 1 show from field results that the proportion of plant food constituents to each other in the fertilizer mixture, when the same quantity of fertilizer is used per acre, has had a marked effect upon the maturity of the crop as measured by the average percentage of the total crop open at the first picking.

TABLE 1.—*Effect of composition of complete fertilizer upon maturity of cotton.*

Fertilizer application per acre	Cotton open at first picking
	%
In Piedmont—Cecil Sandy loam—three years	
Nothing	31
600 lbs. 7-3-2½	51
600 lbs. 7-9-2½	54
600 lbs. 21-3-2½	70
600 lbs. 7-3-7½	43
In Coastal Plain—Norfolk fine sandy loam—six years	
Nothing	44
600 lbs. 7-3-2½	62
600 lbs. 7-9-2½	63
600 lbs. 21-3-2½	72
600 lbs. 7-3-7½	48
800 lbs. 6-4-3	55
800 lbs. 12-4-3	71
800 lbs. 10-3-3	71
800 lbs. 10-7-3	64
800 lbs. 10-4-2	65
800 lbs. 10-4-6	55

In all cases, in field experiments from which information has been secured, it has been found that applications of commercial fertilizers have increased the percentage of cotton open at the first picking as compared with cotton grown where no fertilizer at all was applied. It has been found, too, that the percentage of cotton open at the first picking, with and without fertilizers, was greater when the crop was grown on sandy or sandy loam soils in the Coastal Plain than when grown on clay or clay loam soils of the Piedmont section.

By referring to Table 1, it will be seen that by increasing the percentage of phosphoric acid in a complete fertilizer mixture from 7 to 21 with a 7 3–2½ mixture that the percentage of the total crop open at the first picking was increased from 51 to 70. With this same mixture, increasing the ammonia from 3% to 9% there was only an increase of 3% in cotton open at the first picking; while by increasing the potash from 2½% to 7½% there was a diminution from 70 to 43%. The average percentage of the cotton open where no fertilizers were applied in the Piedmont section was 31 and where fertilizers were used 55.

In the Coastal Plain section, increasing the phosphoric acid from 7% to 21%, with a mixture analyzing 7 3–2½, increased the cotton open at the first picking from 62 to 72%. When ammonia in the same mixture was increased from 3% to 9%, there was practically no change in the percentage open at the first picking, but when the potash was increased from 2½% to 7½%, there was a decrease in the percentage from 72 to 48. Where no fertilizers were used in this section, 44% of the crop was open at the first picking, and assuming the average of the three applications as fairly representative where fertilizers were used 61% opened at the first picking. In all the above, both in the Piedmont and Coastal Plain regions, 600 pounds of fertilizer per acre were used in the drill at planting.

In the Coastal Plain region, where 800 pounds of a fertilizer analyzing somewhat differently were used, the results given below were secured. Using 800 pounds of a mixture analyzing 6 4–3 as compared with the same amount where the phosphoric acid was increased from 6% to 12% in the mixture, there resulted from the use of the latter an increase in the percentage of cotton open at the first picking from 55 to 71. With 800 pounds of a 10 3–3 mixture per acre and increasing the ammonia content from 3% to 7% resulted in a decrease in the percentage open at first picking from 71 to 64. With 800 pounds of a 10–4-2 mixture, there was a decrease in the percentage open at the first picking from 65 to 55 by increasing the potash in the mixture from 2% to 6%.

EFFECT OF DIFFERENT QUANTITIES PER ACRE OF A COMPLETE FERTILIZER OF THE SAME COMPOSITION UPON MATURITY

The average of the results shown in Table 2 indicates that the increase in the quantity of the same fertilizer mixture used per acre in the drill at planting has had a rather marked effect upon the maturity both on representative Piedmont and Coastal Plain soils. In the Piedmont section, it appears from the average results presented in the table that the use of a quantity of something like 300 pounds per acre has had the maximum effect in this respect. The figures in the table, too, show that after the use of a quantity of about 900 pounds per acre is reached, the addition of larger amounts has a decreasing effect upon the percentage of the total cotton open at the first picking. With Coastal Plain soils, an increase of from 300 to 600 pounds per acre in the drill of a 7–3–2½ mixture has increased the percentage of the crop open at the first picking from 55 to 62.

TABLE 2.—*Effects of different quantities of complete fertilizer upon the maturity of cotton.*

Amount of fertilizer per acre	Cotton open at first picking %
In Piedmont—Cecil sandy loam—three years	
Nothing	31
300 lbs. 7–3–2½	61
600 lbs. 7–3–2½	51
900 lbs. 7–3–2½	57
1500 lbs. 7–3–2½	49
In Coastal Plain—Norfolk fine sandy loam—six years	
Nothing	44
300 lbs. 7–3–2½	55
600 lbs. 7–3–2½	62
900 lbs. 7–3–2½	59
1200 lbs. 7–3–2½	60
400 lbs. 10–4–3	63
800 lbs. 10–4–3	69
1200 lbs. 10–4–3	54

The use of from 900 to 1200 pounds per acre on Piedmont soil gave slightly smaller percentages open for the larger amount. Using a mixture analyzing 10–4–3, on Coastal Plain soil, 400 pounds gave 63% open at the first picking and 800 pounds 69%; while the use of 1200 pounds gave 54%, which is a decrease of 15% under that secured by the use of 800 pounds. These results are based upon three years experiments in the Piedmont and six years in the Coastal Plain section.

The carrier of phosphoric acid seems to be the constituent in fertilizer mixtures which exerts the greatest single effect upon the maturity of the crop. When it is varied materially it has an effect on the maturity of the crop as measured by the percentage total crop open at the first picking. Increasing it in the mixture, within limits, tends to hasten maturity, certainly up to an optimum amount. It is assumed that since it hastens the opening of the cotton that it causes the fruit, too, to set earlier. This latter is an important factor to be taken into consideration in the use of commercial fertilizers for cotton when grown under boll-weevil conditions.

MOST PROFITABLE ANALYSES OF FERTILIZERS TO USE FOR IMPORTANT SOIL TYPES OF THE COASTAL PLAIN AND PIEDMONT SECTIONS OF THE STATE

It is fully realized at this time that, in all probability, fertilizer manufacturers cannot ordinarily manufacture fertilizers for different crops, except for use on relatively wide areas. It has been found that there is quite a wide variation in the requirements of analyses of fertilizers best suited for cotton grown on average soils of the Piedmont as compared with those of the Coastal Plain section. There is some variation, of course, even between the soil types of the same region and the same type in different stages of improvement. The more organic matter the soil contains of all types the less ammonia, within limits, will be required.

In the Coastal Plain section, as will be seen in Table 3, the average best analyses is shown by types and for the section as a whole.

TABLE 3.—*Most profitable fertilizer formulas for important North Carolina soil types for cotton with good cultural methods.*

Type of soil	Best fertilizer formulas	Most profitable application, pounds per acre
	In Coastal Plain	
Norfolk fine sandy loam	6-5-3	800
Norfolk sandy loam	8-7-3	600
Marlboro fine sandy loam	6 5-3	600
Portsmouth sandy loam	8 to 9-5 to 6-2 to 3	600 to 900
Dunbar fine sandy loam	7 to 8 4 to 5-3	800
Ruston sandy loam	7 to 8-5 to 6-4 to 5	900
Wickham fine sandy loam	6 to 7-6-5 to 6	900
General for Coastal Plain	8-5-3	600 to 900
	In Piedmont	
Cecil sandy loam	10-4-2	600
Cecil clay loam	10-4-2	600
Georgeville silt loam	10-5-3	600 to 800
Durham coarse sandy loam	10-5-3	800
Alamance silt loam	10-4-4	600
General for Piedmont	10-4 2	600 to 800

These recommendations are derived from the results of a large number of carefully conducted field experiments with cotton in each section. As an average of all of these from the Coastal Plain section, it is suggested that a good safe analyses for the fertilizer for average soils for cotton will be 8% available phosphoric acid, 5% ammonia, and 3% potash. Of course, where the ammonia application is divided, as is frequently done, the percentage of ammonia in the mixture used at planting should be reduced, generally about one-half if as much as 100 to 150 pounds of nitrate of soda or sulfate of ammonia are used per acre as a side-dressing after chopping. On Coastal Plain soils 600 to 800 pounds per acre of this mixture should be used.

For the Piedmont section, analyses of fertilizers are given which have been found best suited for five important types of soil. Here, as in the Coastal Plain section, the analyses of fertilizers are given for soils of each in an average condition. As the amount of organic matter in the soil is increased, the percentage of ammonia in the fertilizer mixture should be reduced accordingly. Taking the average of all these results, the analyses of fertilizers to be used for soils of the Piedmont section in average condition is 10% available phosphoric acid, 4% ammonia, and 2% potash. The most efficient quantity to use in this section for cotton, where good cultural methods are practiced, is from 600 to 800 pounds per acre in the drill at planting.

EFFECT OF QUANTITY OF COMPLETE FERTILIZER UPON YIELD AND PROFIT

As will be seen from the average results given in Table 4, there was a progressive increase in the yield of seed cotton over that where no fertilizer was applied in both the Coastal Plain and Piedmont regions of the state as the quantity of fertilizer was increased by 200-pound increments from 200 to 800 pounds per acre. The net returns for $1.00 invested for fertilizer in the Coastal Plain section

TABLE 4.—*Effect of different quantities of complete fertlizer upon yields and profits in cotton growing.*

Acreage application 7-3-2½ fertilizer Pounds	Acreage increase in yield seed cotton Pounds	Acreage value of increase at 7c per lb.	Cost of fertilizer per acre	Profit per acre over cost of fertilizer	Net returns for $1.00 invested in fertilizer
In Coastal Plain—Edgecombe—seven years					
200	179	$12.53	$3.05	$9.48	$3.11
400	348	24.36	6.10	18.26	2.99
600	667	46.69	9.15	37.54	4.10
800	890	62.30	12.20	50.10	4.11
1000	1000	70.00	15.25	54.75	3.59
In Piedmont—Iredell—five years					
200	402	28.14	3.05	25.90	8.22
400	707	49.49	6.10	43.39	7.11
600	858	60.06	9.15	50.91	5.56
800	939	65.73	12.30	53.53	4.39
1000	1053	73.71	15.25	58.46	3.83

TABLE 5.—*Comparisons of fertilizers having different analyses on different soil types.*

Soil type	County	Seasons of experiments	Contrasts between fertilizer analyses: Poorly suited: Analyses	Contrasts between fertilizer analyses: Poorly suited: Acreage yield seed cotton Pounds	Contrasts between fertilizer analyses: Well suited: Analyses	Contrasts between fertilizer analyses: Well suited: Acreage yield seed cotton Pounds	Difference in yield seed cotton Pounds	Value differences in yield at 7c a lb. for seed cotton	Cost of 700 lbs. of fertilizer of best formula
Dunbar fine sandy loam	Craven	1919	9-3-3	2002	6-6-3	2262	260	$18.20	$11.55
Portsmouth sandy loam	Craven	1921	9-3-3	1421	6-6-3	1800	379	26.53	11.55
Ruston sandy loam	Cumberland	1921 & 1922	9-3-3	1557	6-6-3	1633	76	5.32	11.55
Wickham fine sandy loam	Cumberland	1923	9-3-3	666	6-6-3	1080	414	28.98	11.55
Georgeville silt loam	Randolph	1921 & 1922	9-3-3	1090	12-3-0	1160	70	4.90	8.40

varied from $2.99 where 400 pounds were used to $4.11 where 800 pounds per acre were applied. It will be seen from the average of these results of seven years on Coastal Plain soils that the most economical quantity to apply from the standpoint of returns per $1.00 invested was from 600 to 800 pounds per acre, although the greatest returns per acre were obtained from the use of 1000 pounds.

As an average of five years' field results in the Piedmont section, the returns for $1.00 invested in commercial fertilizers varied from $3.83 to $8.22. From the standpoint of investment per $1.00, the use of 200 pounds was the most efficient. However, from the standpoint of maximum net returns per acre, the use of 1000 pounds gave best results.

PROFITABLENESS OF USING RIGHT ANALYSES

As will be seen by the figures given in Table 5, it has not been uncommon to find that the use of a different analyses, suited to the particular soil, will produce a sufficient increase in yield over the use of the same amount of a fertilizer of a different analyses commonly used by growers to pay for the entire application to the better suited fertilizer.

As will be seen from the data presented in Table 5, the use of a 6 6–3 mixture with cotton gave more than enough increase in yield over that secured by the same quantity per acre of a 9–3–3 mixture used in the drill to pay for the whole of the application of the better adapted mixtures to soil type by the following amounts, for the types of soil indicated in the Coastal Plain section of the State: Dunbar fine sandy loam, $6 65; Portsmouth sandy loam, $4.98; Wickham fine sandy loam, $17.43.

THE PART THE FERTILIZER MANUFACTURER AND HIS FIELD FORCE CAN PLAY IN THE IMPROVEMENT OF THE USE OF FERTILIZERS

It is believed that fertilizer manufacturers, especially through their field forces may exert a very great influence in helping bring about the use of the most efficient kind and amounts of fertilizers by cotton growers of the state. There is no question but that the interests of growers and manufacturers are the same when it comes to securing maximum financial returns per acre for dollars invested by growers in fertilizers. Other things being equal, those manufacturers who supply farmers with fertilizer mixtures which are best suited to their particular conditions and needs will give them the ones which will pay the farmer best to use and will be the ones he will want to use in the future.

THE MOST ECONOMICAL RATE OF APPLICATION OF FERTILIZERS TO COTTON[1]

(Abstract)

C. P. BLACKWELL[2]

Unfortunately, there are few accurate data on the most profitable rate of application of fertilizers for the different sections of the South. The data from the South Carolina Experiment Station, which are by far the most extensive of any of the southern states, have been carefully analyzed to show the cost of production and the net profit per acre with different rates of application.

This analysis shows that at 10c a pound for seed cotton the largest net profit was with 1200 pounds of fertilizer per acre. At 8c per pound the largest net profit was with 800 pounds of fertilizer per acre, and at 6c a pound for seed cotton the largest net profit was with 600 pounds of fertilizer per acre.

One very interesting fact shown here is that as the price of cotton goes down very low the first rates of application to show a loss are the very low rates, the second the very high rates, and the last rates of application to show a loss when the price of cotton goes very low are 600 to 800 pounds per acre. In other words, it would appear that at any price for cotton a reasonably heavy application of fertilizer is a good form of insurance against loss.

In the western part of the cotton belt there are very few accurate data available on the rate of application. In Bradley County, Arkansas, a series of ten tests has been conducted over a period of four years in which application of 100 pounds of nitrate of soda, 250 pounds of acid phosphate and 100 pounds of kainit applied to one acre were compared with one and a half times the same material applied to a second acre. The net profit per acre was calculated to be $10.02 for the lower rate of application, which amounted to 450 pounds, and $13.91 per acre for the higher rate of application which was 675 pounds.

One other factor, which cannot be expressed in figures, is the value of the residual effect of the fertilizer. With heavy applications there must be a considerable amount of fertilizer remaining in the soil after the crop is removed; but there is no accurate method of determining exactly what it is worth. Some investigators believe that the fertilizer remaining in the soil will offset the cost of harvesting the extra crop and possibly also the cost of applying the extra amount of fertilizer. Whether or not this is true, however, cannot be accurately determined.

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EFFECT OF FERTILIZERS ON THE FRUITING ACTIVITIES OF COTTON PLANTS[1]

J. D. Warner[2]

INTRODUCTION

During the past few years detailed fruiting studies have been made on a large number of representative plants on some of the leading varieties of cotton; also the effect of various cultural treatments, spacing, pruning, time of planting, seed treatment and other practices have been rather carefully studied. However, behind all of this, there is perhaps a controlling influence that, in so far as the writer has been able to ascertain, has not received very careful and systematic study by any workers in the South.

One of the most desirable characters in the production of cotton under boll weevil conditions is earliness. It is the early bloom that makes the boll. One bloom during the first two weeks of blooming is worth from five to ten late in the season. Therefore, any practice that will increase the earliness of the crop and hasten its maturity is to be regarded with favor, provided total yield and quality are not sacrificed.

Earliness may be measured in a number of different ways. Early squaring, rapidity of squaring, early blooming, percentage of blooms developing into bolls early in the season, short boll period and other factors which determine the earliness of the cotton crop. Each element in a complete fertilizer may exert a considerable influence on any one or all of these different factors. It may cause the plant to develop in a shorter time and begin fruiting earlier, or cause it to set fruit more rapidly, or perhaps it may have some influence on the length of time required for a boll to develop and open. The work here reported was undertaken with a view of determining the relative value of various fertilizer treatments on these factors.

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[1] Paper read at the meeting of the Agronomy Section of the Association of Southern Agricultural Workers held in Atlanta, Ga., February 3-5, 1926. Received for publication September 10, 1926.

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The results of the cotton fruiting studies reported herein cover only one year's work, therefore, cannot be considered as conclusive. They can be only indicative of what might be expected over a number of years.

PLAN OF EXPERIMENT

The experiment[3] is located at the Pee Dee Experiment Station, Florence, South Carolina, on Orangeburg fine sandy loam soil, although this is not typical of most sandy loams of the Coastal Plain. It was begun in 1914 and since that time has given valuable information on rotation and fertilization of cotton.

The original plan of the experiment was made with a view of determining the relative value in terms of cotton produced of various proportions of each element in a complete fertilizer, as well as the value of a systematic rotation. On three series of plats, a systematic three-year rotation is followed; consisting of cotton; corn and peas; oats followed by peas. On another series, cotton is planted continuously. For cotton, all plats receive an 8-4-4 fertilizer, unless otherwise stated, at the rate of 1000 pounds per acre.

In order to supplement the results as to yields of cotton from these experiments, it was thought advisable to begin more detailed fruiting studies of the cotton plant. Accordingly, plats were selected with a view of determining what effect varying amounts of each element, when applied with constant amounts of the other two, has on fruiting habits. On each of these plats 50 representative plants were selected for the purpose of detailed fruiting study. Blooms were tagged each day, giving the date, and from that time on a complete record was kept including date of shedding, if shed, and date of opening. In addition to this, square and boll counts were made at regular intervals throughout the season.

RESULTS AND DISCUSSION

PHOSPHORUS

Inasmuch as from 90 to 98% of the mature bolls developed from the first five weeks' blooms, it is logical to consider the status of the cotton plant at the end of this period as an indication of the effect of each element in a complete fertilizer on fruiting and on the earliness of the cotton crop.

The total production of blooms through the first five weeks of flowering is very closely correlated with the amount of phosphorus applied as is indicated by the results given in Table 1.

With but few exceptions each increase in the percentage of phos-

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[3] Conducted by the Division of Boll Weevil Control of the South Carolina Agricultural Experiment Station and under the direct supervision of E. E. Hall.

TABLE 1.—*The effect of phosphorus in a complete fertilizer on the earliness of the cotton crop.*

Treatment	Blooms thru fifth week	Percent of season's total put on thru fifth week	Percent at first picking[a]
Continuous			
Check (no fertilizer).....	740	67.9	46.2
No phosphorus.........	1034	52.2	44.1
2% phosphorus........	1554	57.9	41.0
6% phosphorus........	1665	65.5	45.3
8% phosphorus........	1757	71.0	47.0
12% phosphorus........	1556	65.9	47.4
Rotation			
Check (no fertilizer).....	1746	89.9	48.9
No phosphorus	1620	70.5	33.9
2% phosphorus........	2009	68.1	42.2
6% phosphorus........	2554	77.2	47.9
8% phosphorus........	2378	75.3	47.1
12% phosphorus.......	2800	81.5	50.3

[a]Average of five years trials.

phorus in the complete fertilizer resulted in a corresponding increase in the total number of blooms put on through the fifth week and in the percentage that this number was of the total for the season. The conclusion that phosphorus promotes earliness is further strengthened by the percentage of the total crop harvested at first picking. These results correspond in a general way to the blooming records. On the continuous cotton series, more than 8% of phosphoric acid seemed to be of little value. However, on the rotation series, as much as 12% stimulated early season blooming and gave an increase in the percentage harvested at first picking. This difference was probably due to the large quantity of organic matter turned under in previous years, which required more phosphorus to balance the increase in nitrogen through the cover crops.

It is a well-established fact that phosphorus has a tendency to hasten maturity. However, its effect on each factor, or combination of factors, entering into the earliness of the crop is not definitely known. With this fact in view another factor—the boll period—was included in this study. The length of time required for a boll to develop, mature, and open was recorded for every boll appearing on these plats. From these data the average boll period was calculated. The results revealed no significant differences in the effect of varying percentages of phorphorus on the length of the boll period. In all cases, the boll period was abnormally short. The hot dry weather conditions that prevailed throughout the opening season might have largely masked any differences that would have found expression in a normal season.

AMMONIA

Perhaps the one fertilizer element worthy of most careful study is nitrogen. The results presented in Table 2 give some indication as to the behavior of the cotton plant when varying percentages of ammonia in a complete fertilizer are applied.

TABLE 2.—*The effect of ammonia in a complete fertilizer on the earliness of the cotton crop.*

Treatment	Blooms thru fifth week	Percent of season's total put on thru fifth week	Percent at first picking[a]
Continuous			
Check (no fertilizer)	740	67.9	46.2
No ammonia	1416	73.2	44.1
3% ammonia	1969	75.3	48.5
4% ammonia	1757	71.0	47.0
6% ammonia	1645	69.2	52.6
10% ammonia	1790	65.3	49.3
Rotation			
Check (no fertilizer)	1746	89.9	48.9
No ammonia	2534	83.5	52.3
3% ammonia	2465	85.1	47.6
4% ammonia	2378	75.3	47.1
6% ammonia	2977	78.6	46.4
10% ammonia	2623	60.6	38.2

[a] Average of five years' trials.

In compiling these results it was noted that for the first two weeks of flowering varying the percentages of ammonia did not influence to a great extent the number of blooms put on, which in all cases was small. However, for each week thereafter the higher percentages of ammonia greatly stimulated the rate of fruiting. On the continuous series, for the second week's blooming, the plat which received no ammonia put on 118 blooms, while the one which received 10% ammonia put on only 56 blooms. During the fifth week, however, 454 blooms appeared on the no ammonia plat and 835 or almost twice as many on the plat which received 10% ammonia.

In addition to increasing the rate of fruiting, ammonia prolongs the season of rapid fruiting as is indicated by the percentage of season's total put on through the fifth week. This percentage decreased as the percentage of ammonia in the complete fertilizer was increased. By prolonging the season of rapid fruiting, maximum chances for higher yields are obtained.

On the continuous series, the percentage of the total crop harvested at first picking increased as the percentage of ammonia was increased. Where no rotation is practiced and very little organic matter turned under, the addition of nitrogen gave a more balanced fertilizer and apparently hastened the maturity of the plant. In this connection, it is interesting to note that on the continuous series, over a period of five years, 3% ammonia, has given practically the same percentage at first picking and the same yield as no nitrogen where rotated.

Where the systematic rotation was followed and relatively large amounts of organic matter were turned under, the addition of nitrogen seemed to delay slightly the maturity of the plant as is indicated by the percentage at first picking.

POTASH

The results from the use of potash seem to be somewhat similar to those for nitrogen. Although having no significant influence on early season blooming, this element apparently prolongs the season of productive fruiting. This is indicated by the data presented in Table 3.

TABLE 3.—*Effect of potash in a complete fertilizer on the earliness of the cotton crop.*

Treatment	Blooms thru fifth week	Percent of season's total put on thru fifth week	Percent at first picking[a]
		Continuous	
Check (no fertilizer).....	740	67.9	46.2
No potash.............	1675	66.3	46.7
2% potash.............	1641	51.6	35.7
4% potash.............	1757	71.0	47.0
6% potash.............	1657	53.2	36.2
		Rotation	
Check (no fertilizer).....	1746	89.9	48.9
No potash.............	2568	84.2	52.3
2% potash.............	3220	90.8	48.3
4% potash.............	2378	75.3	47.1
6% potash.............	2750	70.9	44.1

[a] Average of five years' trails.

Although no potash gave almost as good results through the fifth week of blooming as did the high percentages of potash; yet the high percentages resulted in a longer season of fruiting, as is indicated by the percentage of season's total put on through the fifth week. Extremely high percentages of potash had a tendency to delay the maturity of the crop where cotton was planted continuously or where rotated. In many cases, potash increases resistance to disease and has other desirable effects aside from its influence on early season fruiting. Any fertilizer treatment that induces maximum fruiting early in the season and prolongs the productive fruiting period might be regarded as valuable for cotton.

SUMMARY

The relative value of each element may be partially determined by its elimination from a complete fertilizer. A summary of the results secured from such treatments is presented in Table 4.

Plats receiving ammonia and potash without phosphorus fruited slowly during the first part of the season and reached their peak late in the season.

Phosphorus and potash in the absence of ammonia resulted in early season fruiting. The fourth week proved to be the most productive; but there were only two weeks rapid fruiting.

TABLE 4.—*The relative value of each element in a complete fertilizer.*

Treatment	Blooms thru fifth week	Percent of season's total put on thru fifth week	Percent at first picking[a]
Continuous			
Check (no fertilizer)....	740	67.9	46.2
Ammonia and potash. .	1034	52.2	44.1
Phosphorus and potash .	1416	73.2	44.1
Phosphorus and ammonia	1675	66.3	46.7
Complete fertilizer.....	1757	71.0	47.0
Rotation			
Check (no fertilizer).....	1746	89.9	48.9
Ammonia and potash.. .	1620	70.5	33.9
Phosphorus and potash .	2534	83.5	52.3
Phosphorus and ammonia	2568	84.2	52.3
Complete fertilizer......	2378	75.3	47.1

[a] Average of five years trials.

Phosphorus and ammonia used alone stimulated early season fruiting; but the period of rapid fruiting appeared to be comparatively restricted through the lack of potash.

The plat which received a complete fertilizer at the rate of 1000 pounds of 8–4–4 fertilizer fruited early in the season and covered three weeks of rapid fruiting, indicating that the plant food was well balanced.

RESULTS OF FERTILIZER EXPERIMENTS WITH COTTON ON ALABAMA SOILS[1]

(Abstract)

J. T. WILLIAMSON[2]

The average of many early experiments of the Alabama Experiment Station shows that a complete fertilizer gives best results on cotton on nearly all Alabama soils.

Recent tests on rate and ratio of applying fertilizer to cotton which have been made on Norfolk, Orangeburg, Dekalb, and Decatur soils show that 100 pounds of nitrate of soda, 200 pounds of acid phosphate, and 25 pounds of muriate of potash is the proper ratio of combining these materials for cotton under the conditions of the tests.

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[1] Abstract of a paper read at the meeting of the Agronomy Section of the Association of Southern Agricultural Workers held at Atlanta, Ga., February 3–5, 1926. Received for publication September 10, 1926.

[2] Associate Agronomist, Alabama Agricultural Experiment Station, Auburn, Ala.

When these fertilizing materials were combined in the above ratio and applied at rates of 325 pounds, 650 pounds, and 975 pounds per acre the greatest average profit came from the use of 650 pounds per acre.

AGRONOMIC AFFAIRS

MINUTES OF MEETING OF THE AGRONOMIC SECTION OF THE ASSOCIATION OF SOUTHERN AGRICULTURAL WORKERS

The annual meeting of the Association of Southern Agricultural Workers was held in Atlanta, Georgia, February 3-5, 1926. At the meeting of the Agronomy Section of the Association, it was voted to accept the invitation of the American Society of Agronomy to become an affiliated Society of the latter organization, with the understanding that a report of the meeting should be sent to the JOURNAL OF THE AMERICAN SOCIETY OF AGRONOMY for publication.

The following officers of the Section were in charge of the preparation and presentation of the program for the meetings: R. Y. Winters, North Carolina Agricultural Experiment Station, *Chairman;* F. E. Boyd, Alabama Agricultural Experiment Station, *Vice-Chairman;* and R. P. Bledsoe, *Secretary.* All sessions of the Section were held at the Biltmore Hotel. The following program of papers was presented:

"The Organization of the South Carolina Soy Bean Growers' Association"—R. W. Hamilton, Extension Specialist, Clemson College, S. C.

(Read by title only)

"Distribution of Cotton Fibres on the Seed."—R. Y. Winters, Director, North Carolina Agricultural Experiment Station, Raleigh, N. C.

(To be published as a bulletin of the Station)

"Relation between Climatic Conditions and the Yield of Soy Beans."—A. F. Kidder, Agronomist, Louisiana Agricultural Experiment Station, Baton Rouge, La.

(Read by title only)

"New Methods with Check Plats."—C. K. McClelland, Assistant Agronomist, Arkansas Agricultural Experiment Station, Favetteville, Ark.

(See This JOURNAL, 18:819-823, 1926)

"The Influence of Liming and of Different Phosphate Fertilizers on the Phosphoric Content of the Soil Solution and Soil Extracts."—F. W. Parker, Soil Chemist, Alabama Agricultural Experiment Station, Auburn, Ala.

(To be published later in SOIL SCIENCE)

"May the Effect of Reliming Follow the Law of Diminishing Returns?"—C. A. Mooers, Director, Tennessee Agricultural Experiment Station, Knoxville, Tenn.

(To be published as a bulletin of the Station)

"The Response to Liming and Fertilization of the Reclaimed Muck Lands of North Carolina."—L. G. Willis, Soil Chemist, North Carolina Agricultural Experiment Station, Raleigh, N. C.

(See abstract elsewhere in this issue)

"Results of Cotton Fertilizer Experiments on Alabama Soil Divisions."—J. T. Williamson, Superintendent of Cooperative Fertilizer Experiments, Alabama Agricultural Experiment Station, Auburn, Ala.

(See abstract elsewhere in this issue)

"What Kind of Fertilizers should be used for Cotton on Different Soil Types."—C. B. Williams, Chief of Agronomy Division, North Carolina Agricultural Experiment Station, Raleigh, N. C.

(See paper elsewhere in this issue)

"The Most Economical Rates of Application of Fertilizers to Cotton."—C. P. Blackwell, Agronomist, Soil Improvement Committee, National Fertilizer Association, Shreveport, La.

(See abstract elsewhere in this issue)

"The Effect of Fertilizers on the Fruiting Activities of the Cotton Plant."—J. D. Warner, Assistant Agronomist, South Carolina Agricultural Experiment Station, Clemson College, S. C.

(See paper elsewhere in this issue)

—J. S. Buie, *Reporter.*

ANNUAL MEETING OF THE NEW ENGLAND SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

The thirteenth annual meeting of New England agronomists, now comprising the New England Section of this Society, will be held at the Boston City Club, Boston, Mass., on December 3 and 4, 1926. The opening session on Friday evening will consist of a dinner, followed by an address by Dr. E. B. Wilson, Chief of the Harvard Bureau of Vital Statistics, on "Statistical Methods." The sessions on Saturday will be devoted to papers on the general topic "Crop Succession." The annual business meeting will be held during the afternoon session.

MINUTES OF THE SUMMER MEETING OF THE WESTERN SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

The 10th annual conference of the Western Section of the American Society of Agronomy was held at the Utah Agricultural College, Logan, Utah, July 22 to 24 inclusive. Approximately 50 agronomists were in attendance, representing the following states: California, Colorado, Idaho, Montana, Oregon, Utah, Washington and Wyoming and the United States Department of Agriculture.

The 1927 meeting will be held at the Moro Experiment Station, Moro, Oregon. D. E. Stephens, Superintendent of the Moro Station, was elected President of the Association, and H. W. Hulbert, head of the Department of Agronomy, University of Idaho, was elected Secretary.

PROGRAM

THURSDAY, JULY 22

MORNING SESSION

Call to order by Prof. E. G. Schafer, head of the Department of Farm Crops, Washington State College.

Roll call.

Address of Welcome, William Peterson, Director of Utah Experiment Station.

Response, E. G. Schafer, President, Western Branch of the American Society of Agronomy.

"Idaho Weeds and Their Relation to Seed Production," Mr. Ralph Bristol, Assistant Extension Agronomist, University of Idaho.

"The Morphology of the Wild Morning Glory (*convolovlus*) in relation to its control by chemical or cultivation methods," Dr. P. B. Kennedy, Agrostologist, California Experiment Station.

AFTERNOON SESSION

"Breeding for Smut Resistance in Oats," By .T. R. Stanton, F. A. Coffman, W. A. Tisdale, G. A. Weibe, B. B. Bayles, and R. W. Smith. Presented by F. A. Coffman, United States Department of Agriculture.

"The Fallacy of Determining a State's Crop Program on a Test of Crop in any Particular Part of Colorado," Prof. Alvin Kezer, Agronomist, Colorado Agricultural College.

"The Native and Introduced Canary Grasses of the Genus Phalaris," Dr. P. B. Kennedy.

"Correlated Inheritance in Wheat," Dr. Geo. Stewart, Agronomist, Utah Agricultural College.

"Water Requirements of Winter Wheat When Grown Under Field Conditions and in Pots," D. E. Stephens, Supt. of Moro, Oregon, Experiment Station.

FRIDAY, JULY 23

MORNING SESSION

"Meeting Agronomic Problems in the Western States," Prof. E. G. Schafer.

"Optimum Stands an Essential in Field Pea Investigations," Prof. H. W. Hulbert, Agronomist, Idaho Experiment Station.

"Improvement of Potatoes in Wyoming," Prof. Glen Hartman, Assistant Agronomist, Wyoming Experiment Station.

"Rice in Japan, China and Malay States," J. W. Jones, Rice Specialist, United States Department of Agriculture.

AFTERNOON SESSION

"A Tentative Classification of the Economic Varieties of Pisum," J. D. Remsberg, Assistant Agronomist, Idaho Experiment Station.

"Distribution of Barley Varieties in California," Victor Florrell, Cereal Investigations, United States Department of Agriculture.

"The Colorado Pinto Bean a Hybrid Variety," F. A. Coffman.

The remainder of the afternoon was spent in a drive through typical farming sections of the famous Cache Valley.

EVENING SESSION

"Residual Effect of Different Irrigation Treatments Upon Crops Grown the Succeeding Year," P. W. Robertson, Assistant Agronomist, Colorado Agricultural Experiment Station.

"Some Studies on the Effect of Manure on an Irrigated Soil," D. W. Pittman, Assistant Agronomist, Utah Experiment Station.

SATURDAY, JULY 24

MORNING SESSION

Visit to the agronomic experimental work of the Utah Station. The studies in the genetics of wheat and the irrigation experiments begun by Dr. Widstoe were of particular interest.

At the business session the following resolution was passed:

WHEREAS, definite information is urgently needed upon the adaptability of domestic forage crop seeds, and whereas, most of the state experiment stations are not financially able to carry on such investigations, most of which are of inter-state interest,

Be it Resolved, That we urge every effort be made to increase the appropriations of the Office of Forage Crop Investigations of the United States Department of Agriculture, sufficient to carry on these investigations in cooperation with State Experiment Stations.—H. W. HULBERT, *Secretary*.

NEWS ITEMS

M. A. McCall, agronomist in charge of cereal agronomy in the Office of Cereal Crops and Diseases, U. S. Department of Agriculture, has taken leave to pursue graduate study in plant morphology, physiology and chemistry at the University of Wisconsin during the current academic year.

John H. Martin, formerly associate agronomist in western wheat investigations, Office of Cereal Crops and Diseases, U. S. Department of Agriculture, obtained his Ph.D. degree in biochemistry and plant physiology at the University of Minnesota last June and has been placed in charge of grain sorghum and broomcorn investigations in the same office. During the autumn months he was engaged on a cooperative economic study of harvesting and storage problems with these crops, chiefly in connection with the use of the combined harvester-thresher. This study is planned and conducted jointly by the Bureaus of Agricultural Economics, Plant Industry, and Public Roads and Rural Engineering, of the U. S. Department of Agriculture and the agricultural experiment stations of Kansas, Oklahoma, and Texas.

R. C. Campbell was appointed assistant agronomist of the Georgia Agricultural Experiment Station for special studies of the quality of cotton fibre, beginning July 1.

R. A. Oakley, senior agronomist in charge of forage crops, U. S. Department of Agriculture, has been in ill health since his return from Europe, where he attended the meeting of the International Agricultural Institute at Rome. He was recuperating at Asheville, North Carolina, during the summer and went to California in early October to spend the winter months.

A. E. V. Richardson, formerly Agricultural Superintendent of Victoria, Australia, is visiting the United States and Canada again in the interest of the Waite Agricultural Research Institute of the University of Adelaide, at Adelaide, South Australia. This institute has been created recently by a gift of £100,000 to which the Government of South Australia will add the equivalent of 3% annually. Prof. Richardson will be remembered also for his former visit to the United States to study methods of dry land agriculture and for his many agronomic publications, including "Wheat and Its Cultivation" in Australia, and a volume on dry farming in America.

Albert F. Woods, president of the University of Maryland and former chief of the Section of Vegetable Physiology and Pathology in the U. S. Department of Agriculture, assumed his new position as Director of Scientific Work in the Department on September 1. His duties include the direction of the educational courses in the Graduate School of the Department.

R. V. Allison, formerly on the staff of the New Jersey Agricultural Experiment Station and for the past two years chemist and soil biologist of the Tropical Research Foundation in Cuba, has been appointed soils specialist of the Everglades Substation in Florida, effective September 1.

Benjamin H. Duddleston, associate agronomist of the Office of Cereal Crops and Diseases, in cooperative experiments in breeding corn for resistance to diseases, and metallic poisons at Purdued University Agricultural Experiment Station, Lafayette, Indiana, is on leave from the U. S. Deprtment of Agriculture to take graduate study in plant breeding and allied subjects at Cornell University during the school year 1926–1927.

Lowell F. Randolph, associate cytologist of the Office of Cereal Crops and Diseases, U. S. Department of Agriculture, in cooperative experiments in the morphology and cytology of maize at Cornell University, is on leave to study under Professors Otto Rosenberg at the Botanical Institute, Stockholm, Sweden; George Tischler at the University of Kiel, Kiel, Germany; and Victor Gregoire at the University of Louvain, Louvain, Belgium, under a fellowship granted by the International Education Board.

F. V. Owen, after completing graduate work in agronomy and genetics at the University of Wisconsin last June, was appointed associate biologist at the Maine Agricultural Experiment Station and stationed at Aroostook Farm in charge of the plant breeding work there.

Director B. Youngblood of the Texas Agricultural Experiment Station has been given a leave of absence to accept an appointment as senior agricultural economist in the Bureau of Agricultural Economics of the U. S. Department of Agriculture, where he will study methods of cotton marketing. Vice-Director A. B. Conner has been appointed acting director and R. E. Karper vice-director of the Texas Station.

M. D. Weldon completed graduate work for the M.A. degree in agronomy at the University of Nebraska in August and has been appointed as research assistant in agronomy at Michigan State College, East Lansing, Mich. George M. Grantham, formerly a research assistant in soils at Michigan State College, has enrolled for graduate work in soils at the University of Nebraska.

George F. Sprague, in charge of cereal investigations at the North Platte Substation, has been given a year's leave of absence for graduate work in genetics and botany at Cornell University. George W. Beadle who has been working on the identification of grasses in prairie hay in Nebraska, in cooperation with the U. S. Department of Agriculture, will also be doing graduate work at Cornell University and serving as an assistant in the Department of Agronomy at the latter institution this year.

ERRATUM

Apparently through a mix-up in the printing room, after the final proofs had been checked and approved, certain mistakes appear in the Registration Nos. of some of the "Standard Varieties of Wheat" which were printed on pages 920 to 922 of the October, 1926, issue of the JOURNAL. The following are the correct Registration Nos. of the varieties in question:

Fultz	48	Wisconsin Pedigree No. 2	148	Kanred	149
Beloglina	150	Bacska	151	Preston	152
Kota	153			Goens	172
Pioneer	154				

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WHAT CAN AGRONOMISTS CONTRIBUTE TO THE SOLUTION OF THE AGRICULTURAL PROBLEM?[1]

C. G. WILLIAMS[2]

I suppose that the most of us are ready to admit that there is an agricultural problem, though we may differ as to its cause and solution. There have been a number of periods of financial distress on the farm when the discussion of situations and remedies was rife, but probably no period when it has been as general as during the last three years. This discussion has not been confined to farmers and the farm press, but noted financiers and more or less distinguished statesmen have had a part in it. The editorial columns of our great daily papers and our financial journals, day after day and week after week, have been filled with investigations and explanations and predictions.

While there have been some differences of opinion as to what is wrong with the farmer, his troubles have been diagnosed in the main as surpluses of one kind or another. Three years ago it was a wheat surplus which commanded our attention. Wm. McNary-Haugen the First was born to rescue wheat from that low index number, as you remember, and was intended to put wheat back to the good old days of 1909 to 1913. But wheat could not wait for Bill the First and climbed back, and then some, with the help of what some of Bill's friends ironically call the divine law of supply and demand.

There are other surpluses, however, and a little later it was said to be corn, though there is good reason for thinking that it may have been a shortage that was troubling the Middle West—a shortage of hogs; together with greatly inflated land values.

Surpluses have occurred from time to time with most of our agricultural and horticultural products, and may be expected to occur for some years to come.

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[1] Presidential address read at the annual meeting of the American Society of Agronomy, at Washington, D. C., November 18, 1926.

[2] Director, Ohio Agricultural Experiment Station, Wooster, Ohio.

A reduced acreage, on the average, will result in reduced production, but there will be exceptional seasons in which this will not hold good. When these exceptions occur ways must be found by the producer to handle his surpluses. He cannot expect the consumer of his products to be a willing party to his own penalization very long.

By cooperative effort he may seek and find new markets. This has been done repeatedly.

He may hold excessive crops of non-perishables for years of low production, which are of unfailing occurrence. Our warehousing facilities make this entirely feasible. By severe grading and culling and by marketing only very high-grade products, he may maintain favorable market conditions which would be utterly demoralized if his entire crop were thrown upon the market. In years of shortage almost anything will be accepted at a fair price. Not so in years of surplus.

These are natural ways of handling surpluses "against which there is no law." It has never been shown that there is any better way. Producers can hardly expect the Federal government to take possession of their plants and render service of this sort. They would not long put up with it in this country if such a service were possible.

No one will deny that prices of many agricultural products are low. We can get together quite an imposing list made up of horses, beef cattle, cotton, corn, oats, hay and other products. But we must remember that there is another list which bears a different relation to "all commodities," namely, hogs, sheep, chickens, butter, wool, potatoes, etc.

These various farm products will be found first in one list and then in the other. As they go from the higher-priced list to the lower we may expect to hear complaints and demands for the "stabilization of prices." No farmer, however, objects to the high price incident to a shortage in production. It is his only salvation. It is extremely doubtful whether Congress, or any farm board selected by the famous "committee of twenty-two," can do a better job of adjusting prices to fit situations than the natural law of supply and demand.

Nobody would worry particularly about surpluses if the price were sufficiently high. Now the chief value of high prices is the margin they allow between the cost of production and the selling price. It is this margin of profit in which the farmer is interested. Price means little to him except as it provides for this margin.

If then the margin between cost of production and selling price is that which is of moment, manifestly anything which reduces the farmer's costs will have as great an effect on his profit as would a similar increase in selling price, and would be better for the farmer than the latter, for an increase in the selling price of his products would tend to decrease the demand for them.

Suppose that a farmer grows wheat at a cost, all told, of 75 cents per bushel and sells it at $1.00 per bushel; there is a profit of 25 cents per bushel. Suppose that his costs are $1.25 per bushel and he sells it at $1.50; there is still a profit of 25 cents per bushel. But in the former case his investment yielded him a profit of 33⅓ %, while in the latter only 20%.

Is it not likely that greater efforts to master the production end of his business would do for the farmer what similar endeavors have done for portions at least of the industrial world? A certain popular automobile is selling now for about 49% of what it brought in 1913, but we hear no complaints in regard to the profits of the manufacturer.

Here, then, is where the agronomist may get in his work, for I want to say to you that all of the problems having to do with economical production have by no means been solved.

What are some of the factors having to do with economical production?

There is the matter of adaptation or adjustment of crops to climates, soils, and seasons.

Most of our states have conducted or are conducting extensive soil surveys. These may well be followed by equally thorough ecological surveys, making possible a more happy, and therefore a more profitable, union of crop and soil.

When such adjustments are made many losses now sustained will be avoided and greater economy of production will be had. Such losses as result from attempts to grow alfalfa on land which is better adapted to alsike clover and timothy.

The growing of potatoes, or tobacco, or sugar beets, or corn, or wheat under conditions where they cannot be expected to be at their best.

The continued try-out of locally new crops like kudzu, beggarweed, velvet beans, teosinte, emmer, spelt, etc., when evidence is available that such efforts will serve only to reduce the profits of the farm.

The use of non-hardy strains of clover and alfalfa.

The cultivation of land which cannot be expected to produce profitable farm crops—land which should be devoted to grazing or forestry.

Then, there is the adaptation of fertilizers to crops and soils—the proper kinds, most profitable amounts to use per acre, and the best place in the rotation to apply them. Experiments have shown that where the same kind and amount of fertilizer were used during the rotation, but shifted from one crop to another, it was possible to affect the results derived from its use by as much as 22%, while at the same time the expense of applying the fertilizer was reduced 50%.

Many of these questions have been quite satisfactorily solved by our agronomists but have not been put into extensive practice by the bulk of our farmers.

While many problems have been fairly well solved for many sections, there yet remain very many problems which have a bearing upon economical production that have not been solved.

For instance, the farmers of the United States are anxiously waiting for a strain of red clover that is as disease-resistant as alsike clover.

For a more acid-tolerant red clover and alfalfa.

For a fine-stemmed, well-leafed, cumarin-free sweet clover plant.

For a variety of winter wheat that has the cold resistance of Turkey, the smut resistance of Trumbull, the yield of Dawson's Golden Chaff, and a stiffness of straw not yet attained by any variety.

For a variety of corn that will resist the auger of the European corn borer, or one that will mature a good crop if planted four to six weeks after the usual planting date.

And then the many questions involved in the matter of crop rotations—if perchance they are not all solved on the morrow. By so simple a thing as a change in the order of two crops grown in a four-year rotation, experiments show that the value of the crops produced during the rotation has been increased over 15%, as a 12-year average.

How frequently may legumes be used with profit in a rotation, and what legumes?

Acreage in standard crops for four-year average, 1922–25.

State	Total cereals	Total clovers	Acreage of cereals to 1 acre of clover
Ohio	7,481,500	1,390,375	5.4
Indiana	8,374,500	1,055,375	7.9
Illinois	16,007,750	1,417,750	11.3
Iowa	17,275,250	1,758,875	9.8
Kansas	16,439,250	1,137,875	14.4
Wisconsin	4,879,000	1,785,750	2.7
Minnesota	9,657,000	1,059,250	9.1
N. Dakota	12,691,250	265,750	47.7

Data gathered by the U. S. Department of Agriculture as to the acreage of corn, oats, wheat, clover, mixed clover and timothy, and alfalfa show the following relationships between cereals and legumes in eight states.

In column 1 is given the average annual total acreage of corn, oats, and wheat for the last four years. In column 2 is given the average annual acreage of clover, plus one-half the acreage of mixed clover and timothy, assuming that this is all that can properly be counted as clover, and the acreage of alfalfa. In column 3 is given the acreage of cereals grown to 1 acre of clover.

There is occasion to think rather seriously as to what this situation means. I do not take it upon myself to say to the states whose acreage of cereals is to clover as ten or more to one that they should make this proportion four or five to one. They might ask me what they should do with this extra clover. I shall simply suggest that such a change in their rotations might, for one thing, put an end to the surpluses which are now worrying them. If the clover and alfalfa could not be utilized in the feeding of present livestock it could be plowed under for soil improvement, which might be as well as to go on growing surplus cereals, and in the language of a defender of the faith now being delivered to the saints, "dump this surplus abroad for what it will bring, and prorate the losses among all producers of the commodity." This is taking agricultural products a long way to find a dumping place

It is very generally agreed that the time is not far distant when we shall have need in this country for all the agricultural products we shall be able to grow. The growing of extra legumes for a few years would put the soil in a better condition to grow the increased acreage of cereals at a profit when that time arrives. Indeed it would at once increase the net profit per acre from cereals, for experiments have shown that the growing of clover one year in three, as compared with one year in five, has increased the yield of corn 7 and more bushels per acre and the yield of wheat 2 to 3 bushels, as the average of many years.

What, then, have we as agronomists to contribute to the solution of the agricultural problem? What is our best thought?

1. Cultivate fewer acres for the time being of the crops of which we are likely to have a surplus, devoting these released acres to special crops adapted to the locality—to legumes, to grazing, and in some few instances to forestry. The present deplorable condition of the cotton market is due in large part, is it not, to the fact that we have increased our acreage of cotton as an average of the last two

years 36% above the average annual acreage of the five years 1909 to 1913? What else could we expect than the present collapse of the cotton market?

The editor of *Wallace's Farmer* in the issue for October 8, 1926, says: "The corn and hog farmers of the Middle-West would get their share of the national income if they would agree to cut the corn acreage in 1927 to a point 15 percent below that of the present year, and at the same time cut their hogs down to fit the corn," which he estimates to be one sow to each 5 acres.

It will not be a simple thing to reduce our corn acreage 15% and our cotton acreage 15 to 25%, but if this will bring the prosperity which our editor believes—and I am inclined to agree with him—it might be as well for our agricultural leaders to center their efforts upon such reduction of acreages rather than upon attempts to handle surpluses at profitable prices to the farmer and thereby encourage still greater surpluses. It may be easier to reduce acreages than to repeal economic laws.

2. Reduce production costs per unit. This will be brought about by:

A.—A wise adjustment of crop to climate and soil.

B.—The most effective use of fertilizers as to kinds, amounts, and place in the rotation.

C.—The use of the best varieties available and the creation of still better varieties.

D.—Handling more acres per man. This has been coming by leaps and bounds and the end is not yet. In an Ohio wheatfield the past summer, 3 men with a combined harvester-thresher binned 745 bushels of wheat in the same number of hours that it took 12 men to thresh 840 bushels from the shock in an adjoining field with the usual threshing outfit. If 3 men with a combine can more than do the work of 12 men in the small grain harvest field, what can save us from "fewer farmers," recently deplored by Ex-Governor Lowden at Syracuse, except legislation to scrap and burn improved machinery and forbid further manufacture of the same? I might add that ten thousand combines were sold the past season in the four states Texas, Oklahoma, Kansas, and Colorado at a cost of some twenty-five million dollars—the demand absorbing the entire production. Agriculture, in line with other industries, has no alternative but to accept this situation. This will mean more or less shifting of population from the farm to the city, and from the city to the farm, which is nature's way of equalizing economic situations.

E.—Doing the different operations of the farm at the right time.

3. Give more attention to the home market. This means the farmer's own home, his nearby city and county, his state and nation. A market in hand is worth two oversea.

As farmers I fear we are not likely to get much direct help in the disposition of our surplus products from national legislation. In so far as our government can help foreign governments to stabilize their currencies we shall put them in a better position to buy our products, for there is little possibility of a country with a debased currency doing much importing. This, and the cancellation of the war debts which has largely been done, will work in the interest of agriculture.

As a debtor nation we had hundreds of millions of dollars which we had to pay Europe each year, and we paid this debt largely with our agricultural products. As a creditor nation the millions are headed this way and not even a Haugen corporation can work the miracle of paying Europe's debt to us with our agricultural surplus, though it might dump the latter in mid-ocean We cannot have important agricultural exports in the future without better provision for imports. International trade is not a one-sided affair.

A moderate reduction in certain tariff rates would doubtless be helpful, but our greatest help will come from the gradual extension of manufacturing industries into our purely agricultural regions. Our great concern is our home market, and our hope lies in expanding it and in adjusting our production to it.

STUDENT'S METHOD AS APPLIED TO FIELD DATA COVERING A PERIOD OF YEARS[1]

WARD H. SACHS[2]

Experiment station workers are constantly striving to improve their methods in order better to arrive at true results, so that more confidence may be placed in the results obtained.

Agronomists and horticulturists necessarily carry on many field tests. Variations in yield, even of adjoining rows of the same variety of a crop, during the same growing season, are not unexpected. Yields of adjoining plats of an experimental field treated in the same manner in all respects are almost sure to vary somewhat. During a period of years the variation in yield of the same plat, treated in as nearly the same manner as possible, is indeed often quite marked.

In order to determine the reliability of an increase of a certain variety or soil treatment over another, various mathematical formulae have been suggested to be used as an aid in the interpretation of the data. A mathematical process for handling experimental data, which has received considerable attention during the past few years, is "Student's Method" (1)[3].

Valuable discussions of Student's method by Love (1) and Love and Brunson (3) are to be found in this JOURNAL. Salmon (4) in a very illuminating article has pointed out some misapplications and limitations in using Student's method to interpret field experiments. As a number of experiment station workers are adopting this method, a further study seems desirable. It is the purpose of this article to discuss further one of the points suggested by Salmon, *viz.*, the effect of season on the application of this method.

As shown by Salmon, the standard deviation depends upon the consistency or uniformity of the differences between the two items compared. Odds, therefore, pile up rapidly, even though the gain may be small, if there is no variation, or only slight variation, between the differences from year to year, while odds will be low if large variations occur.

In order to obtain illustrative material, an attempt was made to secure data covering a period of years showing the benefits derived from under drainage. It appears that the benefits from drainage

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[1] Contribution from the Southern Division Staff, Soil Improvement Committee, National Fertilizer Association, Atlanta, Ga. Received for publication August 21, 1926.

[2] Agronomist.

[3] Reference by number is to "Literature Cited," p. 1067.

have been so obvious on many soils of the Central West that experiment stations have collected little data except on soils where there was a question as to whether drainage would pay. The writer is confident, however, that anyone familiar with the drainage problem will see at once that the assumed conditions shown in Table 1 are those which could be expected. It may be stated that the small amount of data obtained is in line with the assumed conditions.

TABLE 1.—*Hypothetical example of drainage data odds calculated by Student's method.*

Year	Yield per acre in bushels		Gain of drained over undrained in bushels	D	D^2
	Drained	Undrained			
1919	42	40	2	10	100
1920	43	13	30	18	324
1921	54	55	—1	13	169
1922	35	37	—2	14	196
1923	58	44	14	2	4
1924	58	29	29	17	289
			Mean 12		Σ 180.3

$$Z = \frac{12}{13.4} = 0.9 \qquad \sigma = 13.4$$

$$\text{Odds} = 19:1$$

Employing Student's method as an aid in interpreting these data, it will be found that only low odds are obtained, and it must be concluded that drainage is of no significant value on this soil. Yet the farmers may have found that drainage pays, and the experiment station may continue to recommend tile drainage under these very conditions. Where is the discrepancy?

The difficulty here is that Student's method does not take into account the fact that the years in which large differences were obtained were very wet, while the others were very dry and there was no need for drainage. Because the tile was of little or no value in the dry years but a real benefit during the wet years, must it be concluded that tile has not benefited this soil? Obviously not. The farmer who is farming these lands and those who are trying to help him solve his problems are interested more in what the tile will do for him as an average over a period of years. If tile will save his crop, or even give him a good increase, one year, he may be able to afford to let it lie in the ground two or even three years and receive no benefit from it. The tile will be there when the need for it again arises.

In an attempt to determine the value of dusting with calcium arsenate to control the boll weevil, a series of plats may be laid out and the experiment carried on for a number of years. At the end of this period it may be found that in some years dusting showed little or possibly no benefit whatsoever, while in other years large increases may have been secured.

Depending on Student's method for odds, these wide variations in increase from year to year lead to the conclusion that the average increase is not significant, although the entomologist watching the work knows that the years when slight differences were obtained were years when few weevils were present and that the years when large increases were obtained were years when seasonal conditions permitted the weevil to be very destructive Dusting may have been not only of no value in those years when weevils were absent, but may have actually caused a decrease due to the appearance of plant lice following the dusting, although it may have been very much worth while in those seasons when it was needed.

In applying Student's method to field experiments with fertilizers, through a period of years, the same sort of difficulty due to seasonal variation is experienced, although it may not be so apparent. For example, most agronomists will agree that rather liberal applications of potash in the fertilizer for cotton tends to reduce some forms of "rust" and thereby may result in striking increases in seed cotton. This effect of potash was particularly noticeable last year, which was a very dry one. It is also well known that large amounts of potash under certain conditions, particularly wet seasons, will tend to delay maturity, and with the boll weevil unusually active under these moist conditions, the late crop is cut off with little or no increase from the potash

These wide variations in increase from year to year result in low odds, and consequently potash must be considered as giving no significant increase, although in certain years it may have literally saved the crop.

Consider the effect of nitrogen on the growth of the cotton stalk. Who has not seen those wet years when all plats in a fertilizer experiment, including the checks, make a large, sappy growth, with little variation between plats, while in dry or normal years nitrogen causes large increases in growth.

Again these wide variations in difference from year to year give low odds, and it would be concluded that nitrogen had no significant effect on growth in spite of the fact that it did have a marked effect in those years when it was needed.

The increase obtained from a field treatment, whether it be drainage, boll weevil control, or application of fertilizer, is determined to a large extent by the need of the particular treatment. With the need for a particular treatment varying from year to year due to seasonal conditions, why should uniform increases, which are necessary for significant odds, be expected? Under these conditions the uniformity of yearly increase cannot be a measure of the reliability of the average.

If the large increase is correct for the year when there was great need for the treatment and the small increase is correct for the year when the need for the treatment was less or even absent, the average must be correct for this set of conditions, although significant odds may not be shown. It is necessary, however, to continue the field tests long enough that representative seasons are included in the group.

The value of Student's method as a means of studying replications of paired plats during one year should not be overlooked, but the indiscriminate use of this method in connection with field data collected over a period of years may lead to serious error.

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A STUDY OF SOIL TYPES IN RELATION TO UTILIZATION AND MANAGEMENT[1]

W. W. WEIR[2]

In soil science soils are classified on the basis of those distinguishing characteristics which may be observed within their profiles and which have been developed under natural conditions. In dealing with such a classification its practical aspects can hardly be ignored. Thus there arises this question: In a given agricultural area, do the different kinds of soils which farmers recognize, particularly because of differences in handling and yielding qualities, correspond to types when they are classified according to natural and typical characteristics? The question may be stated this way: Do practical farmers recognize distinguishing differences in soils that are classified in soil science? It was with a view to gathering some facts bearing on this problem that this study was made.

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[1] Contribution from Bureau of Soils, U. S. Department of Agriculture, Washington, D. C. Received for publication August 21, 1926.

[2] Associate Soil Technologist.

METHOD OF FIELD STUDY

SURVEY AREA AND SOILS

The survey method was used, and the field selected in this particular study included six counties in north-central Indiana, namely, Tippecanoe, Benton, Warren, Montgomery, Delaware, and Wells. (See Fig. 1.) It is to be noted that within these counties are to be found soils which have been developed under both timber and prairie conditions.

Since general conditions showed that silt loams predominated in these counties, attention was centered upon this class which was selected as the representative of each serial group found. In the field, however, series or type names were not used to distinguish one kind of soil from another, but instead distinctions were made on the basis of dominant characteristics, as follows: Group 1, black silt loams, having bluish-clay subsoils, formed under conditions of almost permanently standing water, in either prairie or timber country; group 2, dark-brown, well-drained soils, formed under conditions of typical prairie-grass vegetation; group 3, yellowish-brown timber soils; group 4, ashy-gray timber soils typically characterized by very tight subsoils; and group 5, black soils underlain by a more or less mottled, faint yellowish-gray or silver-gray clay or silty clay, formed under conditions where water stood intermittently only a part of the time, in either prairie or timber areas.

All observations referred to in this paper were made on arable lands which have been for the most part artificially drained.

COLLECTING FIELD DATA

In collecting suitable field data four factors were given special consideration, namely, the farmers, the soils, the farms, and the crops.

The farmers.—Since in a survey of this kind it is necessary to gather many facts bearing on soil-management practices, the better farmers were selected, through the aid of county agents, bankers, business men, prominent farmers, and by personal contact. In practically every case the farmer selected was a land owner and a man who had had experience with the soils on his farm. In all cases the farmer factor was given first consideration.

The soils.—The next factor considered, after the farmer, was the soil factor. Commonly, much aid was rendered by the farmer in his

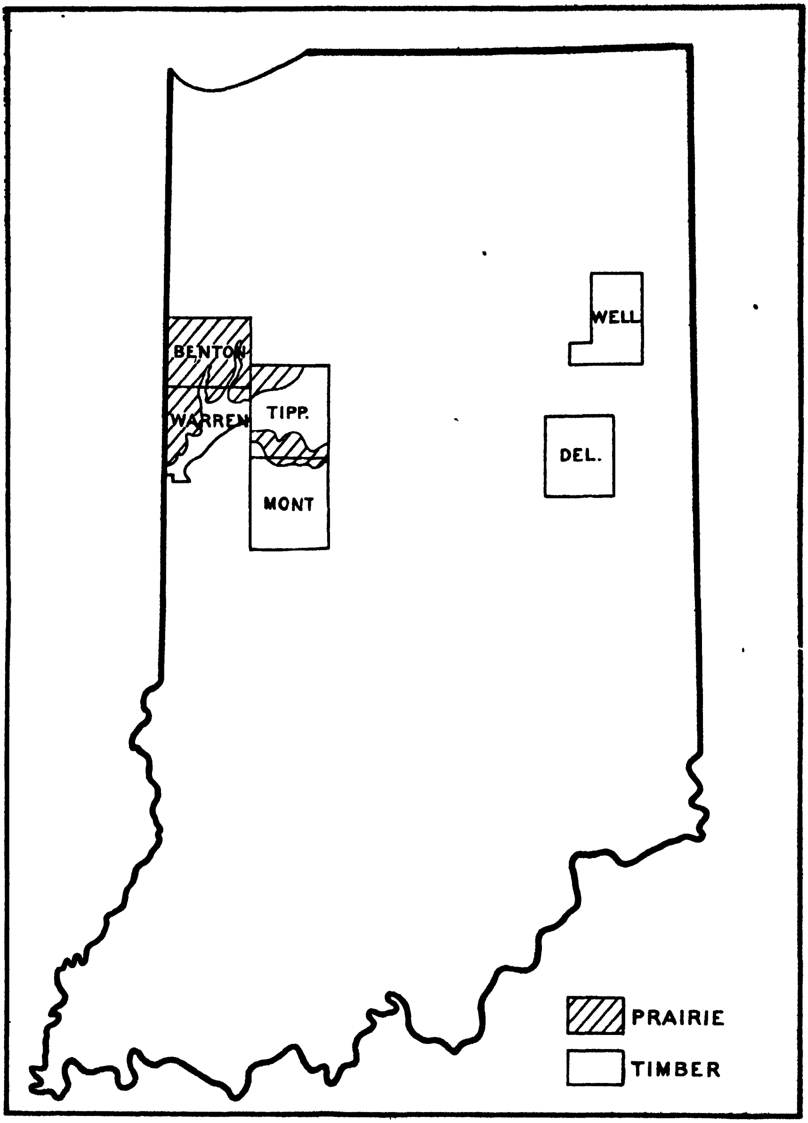

FIG. 1.—Counties in Indiana covered by the survey, including prairie and timber soils.

telling where on his farm "different kinds" of soils might be found. In the farm examination it was the aim to locate areas of soil that would represent one or more of the silt loam groups described in a preceding paragraph. On a suitable spot in each soil area, selected with reference to normal soil development, a 60-inch boring was carefully drawn, by means of a 1-inch auger, and laid on the ground in the order as drawn, and the profile description recorded. When typical soil areas were located and examined, the farmer was asked to give his experiences with the different soils found, relating particularly to his knowledge of their characteristics, handling qualities, and land values, and relating to his soil-management practices and the acre yields obtained, as based on his estimates of 10-year averages. When two or more different kinds of soils were found on a single farm, opportunity was afforded the farmer to give comparative experiences.

The farm.—Representative farms in different parts of a county were selected, especially those farms on which the owner lived and on which he had had farming experience.

The crops.—Since the crops grown on a farm are the true indicators of soil productivity, the same kinds must be used as a basis for comparing the productivity of different soils. In this survey the yields of Indian corn, oats, winter wheat, and hay (clover and timothy) were taken as the basis for making such comparisons in the study of the facts collected.

The immediate object of the survey was the gathering of facts, independent of any preconceived hypothesis. Thus, on each farm that met the conditions briefly described in the foregoing paragraphs, a full description of each kind of soil was recorded without reference to any other description previously recorded either of the same or a different kind of soil. Furthermore, the questions which were asked the farmers were asked in a way not to lead them to give "expected" answers, but in a way that would prompt them to give facts acquired in their farming experiences.

ANALYSIS OF COLLECTED FACTS

SOIL TYPES

On comparing the typical characteristics observed within the profiles of the black silt loams formed under conditions of almost permanently standing water, as found in timber country, with those of the same group (group 1) that have developed under similar conditions but found in prairie areas, it was found that they were practically identical. On correlation, the soils of this first group are herein described as Clyde silt loams. The dark-brown prairie soils of group 2 were correlated with Carrington silt loam; the yellowish-brown timber soils of group 3, with Miami silt loam; and the ashy-gray soils of group 4, with Crosby silt loam. In group 5, the typical characteristics of the silt loams which are in timber areas and which have developed under conditions where water stood intermittently only a part of the time were found to be practically identical with those which have developed under similar conditions but are found in prairie country. On correlation, the soils of this group are herein referred to as Brookston silt loam.

TYPE DESCRIPTIONS

Brief descriptions of the soil types included in this study follow.

Clyde silt loam.—Black silt loam, having a faint grayish cast when dry, grading into a black silty clay loam having a grayish cast. This dark-colored zone is underlain by a bluish clay usually more or less mottled. This bluish clay, in turn, is commonly underlain by a mottled, yellowish-brown till, usually streaked more or less with gray or drab-colored layers or streaks.

Carrington silt loam.—Horizon A (A-1 and A-2): Dark grayish-brown silt loam, usually assuming a grayish cast when dry, which becomes, in depth, somewhat heavier in texture and more yellowish brown in color. Horizon B (B-1 and B-2): Yellowish-brown, rather heavy silt loam grading downward into a yellowish-brown, clayey silt loam which crumbles readily on wetting. Horizon C: Yellowish-brown till, varying from sandy clay to gravelly material.

Miami silt loam.—Horizon A (A-1 and A-2): A rather light yellowish brown silt loam which becomes, in depth, somewhat heavier in texture and more brownish in color. Horizon B (B-1 and B-2): Yellowish-brown, plastic, clayey silt loam grading into a tight, yellowish-brown silty clay or a clay loam. Horizon C: Yellowish-brown glacial till, ranging from a friable clayey silt or silt loam to clayey sand and gravelly material.

Crosby silt loam.—Horizon A (A-1 and A-2): A smooth, ashy-gray silt loam, grading into a faint yellowish-gray or brownish-gray silt loam streaked or tongued with light yellowish-brown clayey silt loam. Horizon B (B-1 and B-2): A compact, light yellowish-brown silty clay or silty clay loam containing ashy-gray streaks or tongues of the grayish material projecting from zone A-2. Zone B-1 grades downward into zone B-2, a very tight, yellowish-brown silty clay, more or less mottled and streaked or flaked (to a greater or less degree) with ashy gray. Horizon C: Yellowish-brown clayey silt to sandy and gravelly glacial till, usually strongly mottled.

Brookston silt loam.—Black silt loam, assuming a grayish cast when dry, which grades into a black silty clay loam having a grayish cast, and which is underlain by a more or less mottled, yellowish, or silver-gray clay or silty clay. The gray clay, in turn, is underlain by a mottled yellowish-brown till.

Typically and under natural conditions all of these soils are more or less acid in their reactions; and they have developed under mean annual rainfall and temperature conditions of practically 38 inches and 51° F., respectively.

FARMERS' RECOGNITION OF DIFFERENT SOILS

Local names.—One of the silt loams which the Indiana farmers recognize as being distinctly different from other soils is that of the Crosby series. Among the common local names given this type are "white-oak land" and "jack-oak land," referring to pin oak, *Quercus palustris*. Clyde silt loam is usually called "gumbo land," "lowest black land," and, because of its zone of bluish clay, "jack-wax soil." Carrington silt loam is commonly referred to as "upland prairie soil," or simply as "prairie soil;" and Miami silt loam, as "sugar land," "hard-maple land," "maple-walnut land," "yellow clay," "timber clay," and "timber clay land." The Brookston silt loam, whether in a timber or prairie country, is commonly described as a "medium soil," "a soil which is in between the lowest black soil and the upland," and, on the prairie, by the oldest settlers, "blue-stem land." One successful timber-soil farmer of long experience distinguishes the Brookston soil from the Miami and the Clyde types by calling it the "Mulatto soil."

Differences recognized in soil management.—The experiences of farmers owning comparatively small areas or few acres of Crosby silt loam have led them to regard this type as one requiring very special attention for profitable crop production. They have learned that it requires tile drainage, manure, commercial fertilizers, and green manure And further, leading farmers are coming to recognize the need of lime and of a short rotation, such as corn, oats or wheat, and clover. Successful farmers possessing larger areas of this kind of soil have early recognized its special need of clover, a short rotation, phosphate, and other fertilizers in fertility maintenance, since it does not possess the enduring qualities as recognized in the Miami silt loams, for example. Wherever Miami and Crosby soils were found on the same farm, the farmer commonly reported that he usually doubled the rate of manure application on the latter.

Well-drained Clyde and Brookston silt loams are considered the best corn soils of Indiana. On these types the cropping system commonly includes two to three successive corn crops, followed by small grain and clover, a modification of the corn-oats-corn-oats cropping system of earlier days. On these soils practically no farm manure is applied, it being used on the Crosby, Miami, and Carrington soils instead. Given both Clyde and Brookston soils on the same farm, usually the latter is given first consideration whenever the question of their fertility maintenance arises.

Differences recognized by acre yields.—In Table 1 is given a summary of the field data, showing the relation of the five soil types to yields of Indian corn, oats, winter wheat, and hay. The soils are arranged in order from the lowest to the highest yields of corn.

TABLE 1.—*Soil types in relation to yields of Indian corn, oats, winter wheat, and hay.*

Yields represent farmers' estimates of 10-year averages.

Soil types	Number of observations by counties						
	Tippecanoe	Benton	Warren	Montgomery	Delaware	Wells	Total observation
Crosby silt loam	29	2	1	6	12	10	60
Miami silt loam	49	6	6	18	5	19	103
Carrington silt loam	13	34	22	0	0	0	69
Brookston silt loam	39	22	15	4	2	3	85
Clyde silt loam	7	19	12	6	6	14	64

Soil types	Average yields per acre			
	Corn in bushels	Oats in bushels	Winter wheat in bushels	Hay (clover and timothy) in tons
Crosby silt loam	30.2	28.5	15.5	1.0
Miami silt loam	38.8	36.8	25.9	1.3
Carrington silt loam	39.7	37.3	19.6	1.2
Brookston silt loam	48.9	43.2	21.1	1.7
Clyde silt loam	52.6	44.5	22.2	1.8

It is to be noted that, for each crop, Crosby silt loam ranks the lowest in production, and Clyde silt loam the highest. The corn yields of the Brookston type, as compared with those of the Miami or Carrington, on the one hand, and those of the Clyde, on the other, clearly explain another reason why Indiana corn growers call the Brookston type a "medium" soil.

The high average estimate of 25.9 bushels of wheat to the acre expresses the farmers' recognition of Miami silt loam as a good wheat soil. This recognition is also expressed by them in terms of high-quality grain. Many farmers possessing Carrington soils have experienced difficulty in growing wheat when they had abandoned the old corn-oats-corn-oats system of cropping and had introduced wheat and clover into the rotation. While, in recent years, the use of available phosphates has encouraged wheat growing, many of the farmers having Carrington silt loams do not regard wheat as a dependable crop.

In studying the comparative yields recorded in Table 1, it should be borne in mind that the Crosby soil receives the most attention, particularly with respect to rotation and the use of farm manure; and that the Miami and Carrington types receive more attention than the Clyde and Brookston soils. If all the soils had received the same treatment, such as is commonly practiced on the two latter soils, in all probability there would have been greater differences in the yields reported. This conclusion is supported by observation made on some farms where areas of Crosby, Miami, and even Carrington soils had not received the attention that had been given like soils on the selected and better managed farms. Naturally, the Crosby silt loam, in particular, is commonly regarded as a poor soil, and without special attention with respect to drainage and fertilization it is commonly counted as submarginal land. Under proper management, however, some of the farmers regarded Crosby silt loam about as good a soil as Miami silt loam. The fact that the order in which the soils are arranged in Table 1 indicates fairly well the degree of attention the farmers have given them in their soil-management practices—most in case of the Crosby silt loams and least in case of the Clyde soils—adds greater interest, technologically, to the contents of the table.

Differences recognized in land values.—From the farmers' point of view, real farm-land values, whether absolute or relative, are usually based on their experiences with different soils, particularly as regards crop yields, handling qualities, and the attention required and expense involved to maintain soil productivity. This survey was extended to include the farmers' recognition of differences in land values as based on the points mentioned. Because of the unstable condition found with respect to absolute land values, attention, in each case, was directed to relative values in the following manner: Since most of the farmers visited had had experience with two or more different soils on their respective farms, each was asked to state his choice of soil for the kind of farming practiced by him. The soil of his choice was given a rating of 100, and the relative rating of each of the other soils was then estimated by the farmer at less than 100. Practically all the ratings were made on the basis of corn as the major crop and assumed well-drained lands. Below is given a summary of these relative ratings, expressed in terms of averages and arranged in groups according to the different silt loams taken into consideration.

Group I	
Clyde	100
Carrington	76

Group II	
Clyde	100
Miami	74

Group III	
Clyde	100
Crosby	58.5

Group IV	
Clyde	100
Brookston	83.5
Carrington	68

Group V	
Clyde	100
Brookston	89
Miami	62

Group VI	
Clyde	100
Miami	85
Crosby	60

Group VII	
Brookston	100
Miami	85.5

Group VIII	
Brookston	100
Carrington	73

Group IX	
Brookston	100
Crosby	57

Group X	
Brookston	100
Miami	83
Crosby	42

Group XI	
Carrington	100
Miami	63

Group XII	
Miami	100
Crosby	69

The above average ratings are in harmony with the data on yields recorded in Table 1. A few of the farmers made their ratings with emphasis on livestock farming rather than on corn, hence the choice of different base relatives, as follows:

Group A	
Miami	100
Clyde	88
Crosby	47

Group B	
Carrington	100
Miami	85
Clyde	75

Group C	
Brookston	100
Clyde	95
Miami	90

These farmers preferred uplands for obvious reasons; for example, a dairyman recognized "high lands" as more suitable for alfalfa and the production of high-quality forage; and a sheep man, for the health of his sheep, preferred upland to lowlands.

SUMMARY

In this paper are reported the results of a field survey covering six counties in north-central Indiana, made with a view, primarily, to studying the relation of soil types to crop production.

The facts collected in this survey show that, when the dominant soils within the counties surveyed are classified according to natural characteristics observed within their profiles, the soils thus classified correspond to the soils to which the farmers have given recognition (1) in local, descriptive names; (2) in their soil-management practices; (3) in their estimates of average yields per acre; and (4) in their estimates of relative land values, as based on their farming experiences.

MINERAL CONSTITUENTS OF THE COTTON PLANT[1]

J. S. McHargue[2]

INTRODUCTION

Evidence pertaining to a more thorough understanding of the mineral nutrients necessary for the growth of plants and animals is of fundamental importance in the science of agriculture.

The writer is interested in the occurrence, distribution, and probable function of the so-called non-essential elements which occur in small quantities in plants and animals which have received their sustenance under natural conditions from the soil. Experimental evidence has been obtained which shows that more than ten elements are necessary for the growth of plants and that manganese has important functions in the vital processes of plants and animals.

The purpose of this paper is to emphasize the fact that small amounts of the elements copper, manganese, and zinc occur in a very interesting way in the different parts of the cotton plant, and incidentally, to report additional data concerning the amount of calcium, magnesium, potassium, sodium, phosphorus, sulfur, and nitrogen contained in the principal parts of the cotton plant.

In 1914, White (5)[3] of the Georgia Experiment Station, and in 1919, Fraps (2) of the Texas Experiment Station, published data concerning the fertilizer constituents contained in the cotton plant. In so far as the conditions are comparable the results for the common fertilizer constituents reported in this paper are in accord with those reported by White and Fraps.

PROCEDURE

SAMPLING

The sample of the plant material upon which the analyses reported in this paper were made was obtained from a field of cotton grown in Mississippi during the season of 1925. The sample consisted of about one dozen plants taken at random during the first part of October and after the first picking of seed cotton had been made. The plants were about 3 feet tall and the branches bore a considerable number of bolls of mature cotton and also a number of immature bolls. The leaves were rather large and of a normal green color, indicating that the plants had made a normal growth to the time at which they were collected. The leaves and bolls were removed from

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[1] Contribution from the laboratory of chemical research, Kentucky Agricultural Experiment Station, Lexington, Ky. Received for publication August 23, 1926.

[2] Research Chemist.

[3] Reference by number is to "Literature Cited," p. 1082.

the branches. The stalks were cut while green into short sections, and each of the different parts of the plant was dried separately for analysis. A 10-pound sample of freshly ginned cotton seed from the first picking of the season of 1925 was obtained also and, after air-drying, the kernels or meats were dissected from the hulls by hand and each part analyzed separately.

METHOD OF ANALYSIS

In the analyses of the leaves, stalks, hulls, and fiber, each of the parts was dried at 100° C. and ashed in a muffle furnace at a temperature which imparted a dull red to the walls of the muffle. Copper was precipitated from a dilute hydrochloric acid solution of the ash by means of hydrogen sulfide and determined by the colorimetric xanthate method (4). The filtrate from the copper was oxidized and made to a definite volume from which aliquots were taken for the remaining constituents of which determinations were made.

In the analyses of the kernels or meats, a different procedure was followed to avoid loss of mineral matter in the process of ashing because of their oily nature. One hundred grams of the kernels were dried at 100° C. and transferred to a 2-liter, round-bottom, pyrex flask placed over a hole on a hot water bath. The organic matter was destroyed by the addition of 25 cc. of concentrated sulfuric acid and about 50 cc. of concentrated nitric acid, the latter being added by drops from a separatory funnel supported above the neck of the flask. After the organic matter was in the main oxidized, the contents of the flask were transferred to a porcelain dish of suitable size which was heated on a sand-bath until the water used to transfer the contents of the flask to the dish and the excess of sulfuric acid were expelled and a dry, brittle residue remained. The dry residue, after cooling, was transferred to quartz dishes and ashed in the muffle furnace. The same procedure was followed with the hydrochloric acid solution of the ash for the several determinations made, as for the leaves, stalks, etc.

Manganese was determined by the colorimetric periodate method (6), and zinc by the ferrocyanide turbidity method (4). The results obtained for the various determinations were calculated to the moisture-free and ash basis and are presented in Table 1.

Total sulfur was determined by Denis' method (1), which consists in saturating a dry portion of the plant material with a solution of copper nitrate, ammonium nitrate, and sodium chloride, evaporating to dryness in a silica dish and heating gently until the contents of the dish are fused and igniting at a low heat in a muffle furnace, cooling, dissolving the residue in dilute hydrochloric acid, filtering, and precipitating sulfates with a solution of barium chloride.

DISCUSSION OF DATA

From the results contained in Table 1 it is apparent that the different parts of the cotton plant have a rather high ash content. On comparison it was found that the leaves and the stalks of this plant contain larger percentages of ash than the corresponding parts of many other important agricultural plants. However, this fact does not necessarily mean that the cotton plant removes more mineral matter per acre from the soil than other plants having a lower ash content because many such crops produce considerably more dry matter per acre than does cotton.

ELEMENTS IN COTTON PLANT NOT PREVIOUSLY REPORTED

Copper was found in each of the different parts of the cotton plant that were examined. However, the largest percentage of copper occurred in the kernels of the seed and was nearly four times as much as was found in any other part of the plant. Accordingly, the ash of the kernels also contained a correspondingly larger percentage of copper than the ash of any other part of the plant.

In the dry matter the copper content of the leaves and hulls was practically the same, but the copper content of the ash of the hulls is nearly ten times the amount found in the ash from the leaves.

The larger percentage of copper occurring in the kernels of the cotton seeds is in accord with previous findings of the author on other seeds of different species of plants, namely, that the seeds contain a larger percentage of copper than the foliage of the same plant. Most of the copper contained in seeds appears to be localized in the germ. For example, if the germs of grains of corn be dissected from the endosperm and the two parts analyzed separately for copper, it will be found that practically all the copper occurs in the germ.

In the kernel of the cotton seed a separation of the radicle from the cotyledons would be a difficult task; however, assuming that such a separation was possible, the author ventures the assertion that a similar association of copper with the radicle of the cotton seed as was found in corn would also maintain. The same relation does maintain with respect to the germs and endosperms of grains of wheat. It is this very striking and interesting association of copper with the vital organs of the plant that leads the author to assume important functions for this element in the economy of the cotton plant. In the dry matter the largest amount of iron occurs in the

TABLE I.—*Mineral constituents contained in the moisture-free substance and ash of different parts of the cotton plant.*

Constituents	Moisture-free condition					Crude ash				
	Leaves	St'lks	K'rn'ls	Hulls	Fiber	Leaves	St'lks	K'rn'ls	Hulls	Fiber
	%	%	%	%	%	%	%	%	%	%
Ash (crude)	25.15	8.667	4.176	2.679	1.12	——	——	——	——	——
Copper, Cu	0.0015	0.0009	0.0054	0.0014	trace	0.0057	0.0104	0.1278	0.0512	trace
Iron, Fe	0.0840	0.0113	0.0150	0.0248	0.019	0.334	0.1310	0.358	0.917	1.687
Manganese, Mn	0.0058	0.0010	0.0013	0.0138	trace	0.023	0.0117	0.029	0.512	trace
Zinc, Zn	0.0037	0.0042	0.0320	0.0022	——	0.0146	0.053	0.767	0.082	——
Calcium, Ca	4.444	1.390	0.1858	0.1367	0.0133	17.65	16.14	4.450	5.06	1.184
Magnesium, Mg	0.519	0.2765	0.3778	0.1295	——	2.064	3.166	9.049	4.79	——
Phosphorus, P	0.693	0.3930	1.794	0.058	0.028	2.752	4.50	42.96	5.00	0.056
Potassium, K	2.170	2.405	1.159	1.143	——	8.62	27.55	27.75	42.26	——
Sodium, Na	0.600	0.443	0.7113	0.877	——	2.36	5.25	17.04	32.46	——
Sulfur, S (total)	2.209	0.434	0.361	0.038	——	——	——	——	——	——
Nitrogen, N	3.18	1.23	7.52	0.62	——	——	——	——	——	——
Protein (N x 6.25)	19.88	7.68	47.00	3.88	——	——	——	——	——	——

leaves, and the next largest percentage of iron in any part of the plant occurs in the hulls of the seed. In the ash of the different parts of the plant the largest percentage of iron occurs in the hulls. In the ash of the kernels the iron content is slightly more than in the ash of the leaves. The ash of the stalks contained approximately one-third of the amount of iron found in the ash of the leaves. The ash from the fiber had a very pronounced brown color and a determination of iron proved that it contained a larger proportion of iron than the ash of some other parts of the plant.

The largest percentages of manganese occurred in dry hulls and in their ash.

The writer (3) has previously shown that the testa or seed coat of some seeds contains a larger percentage of manganese than other parts of the plant. The testa or seed coat of the cotton seed is quite pronounced and undoubtedly contains a much larger percentage of manganese than the hard, horny hull that surrounds it. In dissecting the kernels of cotton seed from the hulls, the testa remains firmly attached to the inside of the hull, and the manganese content of the hulls is undoubtedly enriched because of this fact.

This provision of nature of surrounding the cotyledons of seeds with a membrane rich in manganese is of unusual interest and undoubtedly is indicative of important physiological functions, perhaps the transference of oxygen and other enzymatic changes during the process of germination and growth of the seedling.

The proportion of zinc contained in the different parts of the cotton plant also affords some points for discussion. The percentage of zinc in the kernels of the cotton seed is nearly ten times that in any other part of the cotton plant. The dry kernels of the cotton seed contain approximately 25 times more zinc than manganese; a little more than twice as much zinc as iron; and nearly 6 times more zinc than copper. Similar proportions maintain between the zinc, manganese, iron, and copper in the ash of the kernels. Because zinc occurs in the kernels of the cotton seed in much larger quantities than either copper, iron, or manganese, it is reasonable to assume that this element performs a biological function of no less consequence than any other one of the elements with which it is associated in the kernel of the cotton seed Since large quantities of cottonseed meal are consumed in the food of livestock, this material is a rich source of zinc, copper, and to a less extent, manganese, for such animals as consume portions of it in their food

The raw and unaltered kernels of cotton seed give strong peroxidase and catalase reactions when tested with a fresh solution of gum guaiacum. However, when the commercial product, cottonseed meal, which has been subjected to the steaming process for the removal of the oil contained in the seed, is tested in a similar way for the presence of peroxidases and catalases, negative results are obtained, showing that in the process of heating and extraction of the oil the enzymes are destroyed. It is a well-known fact that compounds of iron, copper, manganese, and zinc give similar reactions with a fresh solution of gum guaiacum. It is quite probable that complex organic compounds of iron, copper, manganese, and zinc are vitally concerned in the oxidative and enzymatic changes that occur in the live tissues of plants.

On the dry basis the leaves of the cotton plant contain three times as much calcium as the stalks; however, the ashes resulting from these two parts of the plant contain nearly equal proportions of calcium. It is evident that the cotton plant requires rather large amounts of calcium for its growth.

In the dry parts of the plant the largest percentage of magnesium occurs in the leaves. However, when the percentages for magnesium are calculated to the ash basis, the largest percentage occurs in the ash from the kernels.

The largest percentage of phosphorus occurs in the dry kernels and also in the ash from the kernels. Nearly ten times more phosphorus occurs in the ash of the kernels than in the ash from any other part of the plant. It is therefore apparent that cottonseed meal is a rich source of phosphorus in the food of domestic animals.

It is an interesting fact that the largest percentage of potassium in the dry parts occurs in the stalks, although the dry leaves contained nearly as much potassium. In the ashes of the different parts of the plant the largest percentage of potassium occurs in the ash of the cotton seed hulls, the next largest percentage occurs in the kernels, and the next largest in the stalks, and the smallest in the ash of the leaves. A similar relationship exists in the sodium content in the different parts of the plant.

The leaves of the cotton plant contain 2.2% sulfur which is more than 5 times as much as either the stalks or kernels and nearly 100 times more sulfur than was found in the hulls.

The dried leaves of the cotton plant contain a little more than 3% nitrogen which is equivalent to nearly 20% protein. Since the leaves also contain rather large percentages of calcium, phosphorus, and sulfur, apparently they should have some value as a food for livestock. The moisture-free kernels of the cotton seed contain 7.52% nitrogen, equivalent to 47.0% protein, and are relatively rich in phosphorus, potassium, magnesium, and calcium. The stalks contain 1.23% nitrogen, which is equivalent to 7.68% protein, and the hulls contain only 0.62% nitrogen, equivalent to 3.88% protein. Since the hulls are used extensively in diluting cottonseed meal, it appears to the writer that the stalks and leaves of the cotton plant might be harvested, ground, and used to as good, if not to better advantage, in diluting cottonseed meal than the hulls.

The large yields of cotton are subject to a favorable combination of several factors, however, as much as 1,200 pounds of seed cotton per acre are frequently reported. The writer has assumed 900 pounds of seed cotton per acre would probably be an average crop, and that 900 pounds of leaves and 1,000 pounds of stalks are discarded products of such a crop.

From the chemical analyses contained in Table 1 and the average yield of the cotton plant per acre the number of pounds of the different elements, reported in the analyses, have been calculated to the air-dry basis and the results presented in Table 2.

The right-hand column of figures in Table 2 contains the aggregate amount of the number of pounds of the different elements occurring in an average crop of cotton plants. The total sum of the different

TABLE 2.—*Pounds per acre of elements contained in an average crop of air-dry cotton plants.*

Parts of plant	Leaves	Stalks	Kernels	Hulls	Fiber	Total
Pounds per acre	800	1,000	300	300	300	2,700
Copper, Cu	0.010	0.008	0.015	0.004	——	0.037
Iron, Fe	0.448	0.103	0.042	0.067	0.057	0.727
Manganese, Mn	0.040	0.009	0.004	0.037	——	0.090
Zinc, Zn	0.026	0.042	0.090	0.006	——	0.164
Calcium, Ca	30.600	12.910	0.522	0.370	0.040	44.442
Magnesium, Mg	3.600	2.533	1.061	0.350	——	7.544
Phosphorus, P	2.112	1.573	5.040	0.157	0.084	8.966
Potassium, K	15.040	22.030	3.225	3.096	——	43.391
Sodium, Na	4.160	4.060	2.010	2.279	——	12.509
Sulfur, S (total)	15.200	4.140	1.080	0.105	——	20.525
Nitrogen, N	22.000	11.750	21.120	1.680	——	46.550
Total	93.236	59.158	34.209	8.151	0.181	184.945

elements per acre of crop is approximately 185 pounds. It is also to be observed that nitrogen, calcium, and potassium occur in the largest quantities and in nearly equal proportions in the summation, while sulfur, phosphorus, and magnesium occur in considerably smaller proportions. It is interesting to note that a larger amount of sodium occurs in the plants than either phosphorus or magnesium. It will be seen that approximately 0.04 pound of copper, 0.1 pound of manganese, and 0.16 pound of zinc per acre occur in and are probably vitally concerned in the production of a crop of cotton.

It is usually assumed that the cotton plant takes less of the plant nutrients from the soil than most any other crop. This assumption is based on the fact that the leaves and stalks of the cotton plant usually are not removed from the soil upon which they were grown; however, since soils that have produced a crop of cotton usually do not bear a cover crop during the winter season, it is more than probable that a considerable proportion of the calcium, potassium, nitrogen, and sulfur contained in the stalks and leaves of the plant at maturity are leached out by the winter rains and carried away in the drainage water before another crop is ready to be grown the following spring. It is also to be observed that quite appreciable amounts of phosphorus, potassium, and nitrogen are permanently lost to the soils producing cotton because large quantities of cottonseed meal are consumed outside the areas in which they were grown.

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THE RATE OF UTILIZATION OF NITROGEN AS AMMONIUM SULFATE BY CORN IN HILL FERTILIZATION STUDIES WITH 2-12-2 FERTILIZER[1]

Frederick B. Smith and Horace J. Harper[2]

The amount of nitrogen which is usually applied in mixed fertilizers used in the hill fertilization of corn is only a small part of the total nitrogen necessary to produce a crop, hence a question arises regarding the necessity of adding any nitrogen. More experimental data must be secured before an answer can be given, but some information may be obtained in regard to the value of mixed fertilizers by determining whether the increased rate of growth of the tops of young plants which have been hill fertilized is due merely to the fertilizer applied or whether a larger root system has been produced. If the latter has occurred, the plant will obtain more food from the soil, and the growth and maturity of the crop will be hastened.

EXPERIMENTAL

In the following investigation, an attempt was made to determine the rate at which the nitrogen in ammonium sulfate, applied in the hill with acid phosphate and potassium chloride, was utilized by the corn plant, and also to determine whether or not the corn plant in its early development was feeding mainly on the nitrogen applied or whether the root system was actually gathering more nitrogen from the surrounding soil than was true in the case of the unfertilized plants. In all cases the fertilizer was mixed thoroughly with a layer of soil about 3 inches wide, 12 inches long, and 1 inch deep.

A screen made of four-mesh black wire was placed at a depth of 3 inches from the surface of the soil, a layer of soil mixed with fertilizer placed upon it, four kernels of corn planted in the middle of the area, and another screen placed on top. Two inches of soil were

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[2] Graduate Assistant and Associate Professor of Soils, respectively.

placed on the upper screen. With such an arrangement it was easy to sample the fertilized soil and the area 1 inch below the fertilized zone in order to study the rate at which the nitrogen was used by the corn plant. The study was made on a Carrington loam which was slightly acid and contained about 3,000 pounds of total nitrogen and 900 pounds of total phosphorus per acre.

The corn was planted on May 14 and the first samples of soil were taken on June 19. Two samples were taken from each hill of corn. The fertilized soil between the wires made up the first sample and the soil taken 1 inch deep and directly beneath the lower wire made up the second sample. The latter sample was taken in order to determine whether there was very much downward movement of the ammonium sulfate applied, and also to obtain any nitrate which may have been leached out of the fertilized zone by rain. Samples were taken again on June 29 and on July 13. At the last sampling the corn had tasseled and silks were beginning to appear on the fertilized plants. All samples were analyzed for nitrate and ammonia. The amount of nitrate was determined by reduction with Devarda alloy. The ammonia was determined by direct distillation of the soil with magnesium oxide. This method was used since the differences obtained between the fertilized and unfertilized soils were the important consideration rather than the actual amount of ammonia produced

The results of the analyses of nitrate and ammonia in the different soil samples are given in Table 1. The data from the hills receiving no treatment are the averages of two samples, while the data from the treated hills are the averages of three samples

The indications are that at first the ammonia in the fertilizer was nitrified more rapidly than the nitrate was taken up by the plant. After the first sampling, however, the nitrate was used by the corn plant as rapidly as it was formed. The amount of nitrogen added per hill in the 100-pound application of fertilizer was 0.225 gram and in the 200-pound application 0.450 gram. It is evident that there was a rapid change in both the nitrate and ammonia content of the soil at the second sampling, and on July 13 the analyses indicated that very little of the nitrogen added in the fertilizer was left in the soil.

The percentage of total nitrogen in the corn plants differently treated is given in Table 2. The average dry weights of the plants in the treated and untreated hills are also given, and from these data the amount of nitrogen in the plants from the fertilized and unfertilized hills was calculated.

In all cases the fertilized plants contained more total nitrogen than

TABLE 1.—*Rate at which nitrogen in ammonium sulfate was utilized by corn plants when applied in the hill with a 2–12–2 fertilizer.*

Treatment	Rate in pounds per acre in hill		Pounds N as NO_3 per 2,000,000 lbs. soil			Pounds N as NH_3 per 2,000,000 lbs. soil		
			June 17	June 29	July 13	June 17	June 29	July 13
None		Surface	21.7	6.0	8.2	86.7	17.0	24.0
		Subsurface	34.5	13.1	10.5	60.5	18.0	27.2
2–12–2	100	Surface	50.4	12.0	23.4	154.2	49.3	20.1
		Subsurface	40.4	24.4	16.7	45.0	30.1	13.5
2–12–2	200	Surface	82.3	29.4	18.2	435.3	107.0	59.8
		Subsurface	63.0	22.9	18.9	123.3	56.3	54.3

TABLE 2.—*Rate of growth and analyses of corn plants fertilized in the hill with a 2–12–2 fertilizer containing nitrogen as ammonium sulfate.*

Treatment	Rate in pounds per acre in hill	Dry weight per hill in grams			Total percentage N in corn plants			Total N in corn plants in grams		
		June 17	June 29	July 13	June 17	June 29	July 13	June 17	June 29	July 13
None		5.96	21.95	145.5	2.85	3.97	2.72	0.168	0.857	3.967
2–12–2	100	8.18	48.03	195.3	2.60	3.77	2.33	0.212	1.810	4.550
2–12–2	200	10.83	33.83	240.3	2.98	3.08	2.20	0.323	1.043	5.280

the unfertilized plants. At the first sampling the difference between the nitrogen in the fertilized and unfertilized plants was not equal to the amount of nitrogen applied in the fertilizer. At the second sampling the difference in case of the 200-pound application of fertilizer was still less than the amount of nitrogen applied, but the difference between the amount of nitrogen in the plants receiving 100 pounds of fertilizer per acre applied in the hill and in the unfertilized plants was much greater than the amount of nitrogen added in the fertilizer. At the last sampling the difference between the nitrogen content of the fertilized and unfertilized plants was also greater than the total nitrogen applied in the fertilizer. This would indicate that the fertilizer applied to the corn increased the size of the root systems of the fertilized plants, and as a result more plant food was obtained from the surrounding soil which was not available to the unfertilized plants because of their smaller root systems.

Truog, et al[3], found that hill fertilization increased the size of the root system of young corn plants over that of plants which had not been fertilized, but not in proportion to the increase which occurred in the growth of the tops.

Millar[4] has shown that hill fertilization of corn does not restrict root development, and has suggested that in case of drought the injury to fertilized plants is due to a greater loss of moisture by evaporation since the leaf area of fertilized plants is greater than that of unfertilized plants. This is true in soils ot medium to low fertility.

It is not an unusual occurrence, however, for hill-fertilized plats to develop more rapidly in the early part of the season and yet show no increase in yield over plats which have received no fertilization. This is due no doubt to a favorable growing season in which the unfertilized plants have had enough time to catch up with the fertilized plants and reach maturity before frost. However, in sections of the country where short growing seasons prevail and nitrogen is not the limiting factor in crop production, or under unfavorable weather conditions, hill fertilization may be practiced in order to hasten the early growth of the crop, when it can take advantage of the larger amounts of available plant food which are produced during the short period of hot weather during the summer and reach maturity before frost.

More data along this line should be obtained under conditions which are less favorable for crop growth than those at this station before definite recommendations in regard to hill fertilization can be made.

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[3] TRUOG, E., et al. Fertilizer experiments. Wis. Agr. Exp. Sta. Res. Bul. 65. 1925.

[4] MILLAR, C. E. Hill fertilization of corn. Mich. Agr. Exp. Sta. Qr. Bul., 5:69–73. 1922.

SUMMARY

A study was made of the rate at which corn plants use the nitrogen from ammonium sulfate when applied in the hill in the same plane with the seed with acid phosphate and potassium chloride in amounts per acre equivalent to 100 and 200 pounds of a 2–12–2 fertilizer. In eight weeks after the fertilizer was applied nearly all of the nitrogen added had been taken up by the corn plants. At that time the difference between the amount of nitrogen in the fertilized and unfertilized plants was several times greater than the amount of nitrogen applied to the fertilized plants. This indicates that the root systems of the fertilized plants were considerably larger than those of the unfertilized plants, since much larger amounts of nitrogen were obtained from the surrounding soil by the fertilized plants than were secured by the plants receiving no fertilization.

EFFECT OF ALTERNATE FREEZING AND THAWING ON THE IMPERMEABILITY OF ALFALFA AND DODDER SEEDS[1]

A. R. MIDGLEY[2]

It has long been known that ordinary commercial alfalfa and clover seeds contain many impermeable seeds. Much experimental work has been done in trying to reduce this impermeability and cause a higher percentage of these seeds to germinate. It has been generally accepted, without much experimental data, that alternate freezing and thawing will greatly reduce this impermeability. The work that follows deals directly with the effect of alternate freezing and thawing on impermeable alfalfa and dodder seeds.

REVIEW OF LITERATURE

Harrington (3)[3] gives the following definition, "Impermeable seeds are seeds whose coats are impermeable to water at ordinary temperatures favorable for germination."

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[1] A thesis submitted to the Department of Agronomy, Utah Agricultural College, Logan, Utah, in partial fulfilment of the requirement for the degree of master of arts, June, 1926. Received for publication September 9, 1926.

[2] Formerly graduate student at Utah Agricultural College; now Assistant in Agronomy, University of Wisconsin, Madison, Wis. The writer wishes to express appreciation for helpful suggestions offered by Dr. Geo. Stewart under whose direction these experiments were made.

[3] Reference by number is to "Literature Cited," p. 1098.

This is a better term than "hard" seeds or "hard-coated" seeds as the term "impermeable" implies that they are capable of becoming permeable.

As to causes of impermeability, Rees (4) states that a cuticle is secreted outside the palisade cells and that this is permeated through and through with particles of fat or wax. Harrington (3) states that it is not caused by a difference in soil, season, or climate. He claims that the exact cause is yet unknown.

Harrington also states that it is impossible to distinguish impermeable seeds except by testing their ability to absorb water at germinating temperatures. A cross section of an impermeable seed under the microscope usually shows a thicker malpighian layer in the seed coat, and certain canals will be closed.

Concentrated sulfuric acid and scarification are valuable in destroying the hard seed coat so that the seed may become permeable and germinate. Either method is valuable in getting a quick germination test for impermeable seed. Graber (2) states that alfalfa seed should be scarified before planting if it contains over 10% impermeable seed.

Staker (5) and Stewart (6) found that heat (60° to 90° C.) greatly reduced the impermeability and increased the germination of alfalfa seed Rees states that it melts or dearranges the wax in the seed coat. DeCandolle (1) subjected alfalfa seed to the low temperature of liquid hydrogen (—250° to —255° C.) for six hours, and when the seeds were tested they gave a complete and perfect germination. He claims that the amount of heat and cold the seeds can withstand varies with their moisture content.

PROCEDURE

The alfalfa seed used was a composite sample obtained from various growers in Duchesne County, Utah. The impermeable seed taken from this sample was used throughout the experiment. The colored samples used were taken from different sources and were carefully separated into six fractions as follows: Light green, dark green, shrivelled green, light brown, dark brown, and shrivelled brown.

Dodder seed was also used in the experiment as it has long been known to remain in the ground for many years and germinate very slowly. The large-seeded dodder was the only kind used in the experiment as it is found more frequently in commercial alfalfa seed due to the fact that the small-seeded varieties can be separated out with proper screens.

In order to obtain impermeable alfalfa seed, seeds from the original sample were sprinkled on moistened filter paper and allowed to germinate for ten days. The seeds that did not germinate after being in the germinating room for ten days were placed in a package and labeled "Impermeable Seed."

Two refrigerating rooms of the Dairy Department were used in freezing the seeds. The first room had an outside entrance and the door was opened often during the day, therefore its temperature varied greatly. It was found, however, to fluctuate between 0° and —10°C. (32° to 14°F.). The second room opened into the first, therefore its temperature remained more constant and colder. Thermometer readings showed that it varied between —15° and —20°C. (5° to—4°F.).

In order to germinate the seeds before or after freezing they were placed on moistened filter paper laid over wet sand. Tin plates about 6 inches in diameter were used to hold the sand. Throughout the experiment, the sand and paper were kept moist. The germinating room was kept about 23°C. or 70°F. Unless otherwise stated, impermeable seed was always used and 100 seeds set on each pan.

RESULTS OF ALFALFA EXPERIMENTS

EFFECT OF ALTERNATE FREEZING AND THAWING WITH DIFFERENT TEMPERATURES OF FREEZING

Does the intensity of freezing have any influence in reducing the number of impermeable seeds in alfalfa? To find out what influence this had, the two refrigerating rooms were used for freezing the seeds. Ten plates containing 100 seeds on each were used in the experiment. The plates were carefully labeled and half of them used for each room. At the close of each week they were placed in their respective freezing rooms and frozen for about 36 hours (Saturday night to Monday morning). They were removed Monday morning of each week and placed in the germinating room, where they were allowed to germinate for six days. Saturday of each week, the number that had germinated in each pan was counted. The remaining seeds were then returned to their respective freezing rooms and the above process repeated. The experiment was started January 6, 1926. The seeds were always kept moist.

Table 1 shows the number of alfalfa seeds that germinated after each freezing in the first room with an average freezing temperature of —5°C., and Table 2 the number that germinated after each freezing in the second room with an average freezing temperature of —15°C.

TABLE 1.—*Effect of alternate freezing and thawing on impermeable alfalfa seed with an average freezing temperature of —5°C.*

Plate No.	Date germinated seeds were counted														
	January			February					March				April		
	12	20	26	1	6	12	19	27	5	13	20	27	3	10	Total
A	23	5	3	2	1	0	1	2	0	1	2	8	2	2	52
B	25	4	3	3	4	1	2	8	1	2	1	4	3	0	61
C	22	8	6	5	4	0	1	3	1	1	1	2	3	0	57
D	21	15	4	5	2	0	4	1	1	0	0	3	4	1	61
E	20	5	3	4	2	2	3	2	0	3	4	2	3	2	55
Average	22.2	7.4	4.0	3.9	2.6	0.6	2.2	3.2	0.6	1.4	1.6	3.8	3	1	57.2

TABLE 2.—*Effect of alternate freezing and thawing on impermeable alfalfa seed with an average freezing temperature of —15°C.*

Plate No.	Date germinated seeds were counted														
	January			February					March				April		Total
	12	20	26	1	6	12	19	27	5	13	20	27	3	10	
F	25	5	3	5	2	2	2	2	2	2	2	3	4	1	60
G	28	8	7	8	0	0	1	1	1	1	2	3	5	0	65
H	24	3	7	5	3	0	0	2	1	2	3	3	3	2	58
I	23	4	3	1	2	0	2	4	4	0	2	4	2	3	54
J	25	3	4	4	2	2	0	2	2	1	4	1	3	3	56
Average	25.0	4.6	4.8	4.6	1.8	0.8	1.0	1.2	2.0	1.2	2.6	2.8	3.4	1.8	58.6

An examination of the data given in Tables 1 and 2 seems to indicate that the intensity of freezing has no effect on the number germinating or on the rate of germination. Probably the most striking result in this experiment is the small effect that alternate freezing and thawing has on impermeable alfalfa seed. A large number (averaging 23%) was found to germinate after the first freezing, but the number germinating for each subsequent freezing was very small, yielding an average germination of 2.5% for each week.

The hardiness of alfalfa seed to freezing and thawing temperatures is also very noticeable. During the 16 weeks of alternate freezing and germinating, none of the seeds were killed. All seeds that became permeable germinated readily.

EFFECT OF TIME ON DRY SEED, WITH AND WITHOUT DRY FREEZING

It has long been known that alfalfa seed will become permeable with age, if kept long enough, even in a dry condition. To find out what effect time had in reducing the impermeability of alfalfa seed the following experiment was performed. In this experiment the original sample from which the impermeable seeds were taken was also used. It will be labeled "Sample Seed" in order to distinguish it from the "hard-coated" or impermeable seed.

A small portion of "Sample Seeds" and impermeable seeds were placed in separate dry sacks, carefully labeled, and subjected to two or three dry freezings. Three hundred seeds of each were then set out to germinate for ten days. Similar portions of "Sample" and impermeable seed treated in like manner except that they were kept under room temperatures and were not subjected to any cold. The results are shown in Table 3.

TABLE 3.—*Effect of time on alfalfa seed while in a dry condition, with and without dry freezing.*

Description of sample	Oct. 15	Apr. 15	Number increase	Number increase over nonfrozen
Sample seed (no freezing)....	16	24	8	
Sample seed (dry freezing)...	41	49	8	25
Impermeable seed (no freezing)	0	7	7	
Impermeable seed (dry freezing)	22	30	8	23

An examination of Table 3 shows that alfalfa seed does become permeable with age. It is very interesting to note that the number becoming permeable during the six months (October 15 to April 15) was nearly the same in each case, producing about eight permeable seeds for that period of time.

Dry freezing is shown to have some value in reducing the number of impermeable seeds. The increase due to dry freezing is practically the same in the "Sample" as in the impermeable seed. These results would seem to indicate that the seeds which are kept in store-houses where they are subjected to natural changes in temperature would have their impermeability reduced.

EFFECT OF DIFFERENT DURATIONS OF WET FREEZING

Does the length of time a seed is frozen influence its permeability? To find out what effect different durations of freezing have on impermeable alfalfa seed, five samples were frozen for one hour, two hours, four hours, eight hours, and two months, respectively. A check sample was also used to note the effect of an unfrozen sample. No less than one hour could be used as it required that length of time to freeze the seeds completely. The temperature of the freezing room was —15°C. One hundred seeds in each of three pans were used in each case. They were prepared in the ordinary way for germination, with the seeds thoroughly wet. They were placed in the freezing room for the desired length of time, frozen only once, and removed to the germinating room. After six days the number germinated were counted and recorded. Table 4 gives the average germination on a 100-seed basis.

TABLE 4.—*Effect of different durations of freezing.*

Duration of freeze	Number germinating
One hour	21
Two hours	22
Four hours	20
Eight hours	25
60 days	24
Check (no freezing)	5

Table 4 shows that there is practically no difference due to the length of time the seeds are frozen. The results of continuous freezing for 60 days were practically the same as a one- or two-hour freeze.

EFFECT OF DIFFERENT LENGTHS OF TIME OF THAWING WITH SUBSEQUENT FREEZING

Does the length of time that impermeable seeds are allowed to thaw between freezings have any effect on germination? It is thought that if alfalfa seed is sown in early fall the impermeable seeds that do not germinate in the fall will do so the next spring, after being subjected to the natural freezing and thawing that goes on in the soil during the winter and early spring, due to a breaking up of the hard seed coat by the alternate freezing and thawing, thus causing the seed to become permeable.

During the warm winter months and early spring there are different lengths of thawing during the day with a heavy freeze the following night. To find out, as near as possible, what effect this has on impermeable seed, the following experiment was conducted. Four periods of thawing were used as follows: 2 hours, 4 hours, 8 hours, and 15 hours. After each thaw the seeds were frozen, and this was repeated for five consecutive days in the one case and ten consecutive days in the other. With the exception of the 15-hour thaw, the seeds were removed from the refrigerator each morning at eight o'clock. The 2-hour samples were replaced at ten o'clock, the 4-hour samples were replaced at twelve o'clock, and the 8-hour samples at four or five o'clock. The 15-hour samples were left in the germinating room over night from 5 p. m. to 8 a. m. and frozen during the day. After the five- and ten-day period of treatment the seeds were allowed to germinate for six days. To insure greater accuracy in the results, triplicate tests were run and repeated on three different dates. Table 5 shows the number germinating and the number dead after the five-day treatment, and the results for the ten-day treatment are given in Table 6.

TABLE 5.—*Effect on germination of impermeable alfalfa seed of different lengths of thawing each day for five consecutive days.*

Treatment	Number germinated	Number dead	Total number softened	Number hard seed
2-hour thaw..............	21	9	30	70
4-hour thaw..............	10	20	30	70
8-hour thaw..............	6	24	30	70
15-hour thaw..............	1	31	32	68

TABLE 6.—*Effect on germination of impermeable alfalfa seed of different lengths of thawing each day for ten consecutive days.*

Treatment	Number germinated	Number dead	Total number softened	Number hard seed
2-hour thaw..............	8	23	31	69
4-hour thaw..............	6	27	33	67
8-hour thaw..............	3	29	32	68
15-hour thaw..............	No sample			

An examination of the above tables shows that as the length of thaw increased the number of dead seeds increased, with a corresponding lower number germinating; and that the total number that became permeable or softened was practically the same regardless of the length of thaw.

By a comparison of the two tables, it is seen that a 2-hour thaw for ten days produced as many dead seed as an 8-hour thaw for five days. In addition to this it is also noticed that the ten-day treatment reduced the number of hard seeds on an average of only two over the five-day treatment. This seems to indicate that the extra five days of alternate freezing and thawing had very little influence in reducing the impermeability. In general, the above experiment shows that the seeds that became permeable by freezing and began to germinate were killed by the subsequent freezing.

The above results are also substantiated by a small experiment that was started on March 1. Three pans each containing 100 impermeable alfalfa seeds were moistened and the pans exposed to natural freezing and thawing in an orchard. On March 31, the seeds were examined. It was found that an average of 30 seeds in each pan had become permeable but were dead as none of them germinated after being in the germinating room for five days.

EFFECT OF ALTERNATE FREEZING AND THAWING OF SEEDS OF DIFFERENT COLORS

It is generally supposed that the color of alfalfa seed is related to its vitality (6). If this is the case, which color has the greater vitality and which color contains the greatest number of impermeable seed? In order to determine the number of impermeable seeds for each color fraction, the following experiment was carried out. Alfalfa seeds which had previously been separated into six colors were counted and set to germinate in the usual manner for six days. The number germinating and the number of hard seeds remaining for each color are shown in columns 1 and 2 of Table 7.

The number of impermeable seed in each color fraction was so small that no attempt was made to separate them. In order to ascertain the effect of freezing and thawing on the different color fractions, samples of each color were run for five consecutive days. Each day they were allowed to thaw for the desired length of time and then returned to the freezing room. Group A was allowed to thaw for four hours each day and group B for eight hours. The results in percentage are recorded in Table 7.

TABLE 7.—*Effect of alternate freezing and thawing for five consecutive days on alfalfa seeds of different colors.*

Colors	Check, no freezing			4-hour thaw			8-hour thaw		
	No. germinated	No. hard	No. dead	No. germinated	No. hard	No. dead	No. germinated	No. hard	No. dead
Light brown......	52	8	40	8	4	88	4	1	95
Light green......	40	57	3	14	54	32	6	34	60
Dark green......	32	10	58	10	4	86	4	2	94
Dark brown......	32	5	63	4	0	96	2	0	98
Shrivelled green...	27	20	53	4	10	86	4	8	88
Shrivelled brown..	11	4	85	0	2	98	0	0	100

An examination of the data given in Table 7 shows that the green contained more impermeable seeds than the brown. This is to be expected, as the green color approaches more nearly the normal bright yellow color than does the brown. It is a noticeable fact that before freezing the light brown gave a higher germination than the light green. This is due to the large percentage of impermeable seed in the latter. The brown seeds appear to have less vitality than the green seeds, for in every case freezing and thawing produced a larger number of dead seed in the brown than in the respective green samples.

EFFECT OF CONTINUED MOISTURE WITHOUT FREEZING

In the experiment on alternate freezing and thawing of alfalfa seed, it was noted that the seed became permeable very slowly. The effect of freezing in reducing the impermeability appeared to be very slight. The question then arose, would not the same seeds have germinated without freezing if they were kept in a moist condition for the same length of time? With this in view the following experiment was conducted. Four plates containing 100 seeds each were used. In half of these the seeds were placed in soil and in the others on moist filter paper in the usual manner for germination. One reason for using soil was to check it with the ordinary method on filter paper. In preparing the soil sample two of the plates were partly filled with soil which was then moistened and 100 seeds scattered over the moist soil. Just enough soil was then sprinkled over the seeds to cover them. The seeds were always kept moist, and at the end of each week they were examined for germination. The only dates recorded are those on which seeds germinated. The experiment was started January 4, 1926. Tables 8 and 9 give the results.

TABLE 8.—*Time required for alfalfa seed to germinate in moist soil without freezing.*

Plate No.	Dates when seeds were found to germinate									
	Jan.			Feb.		Mar.			Apr.	
	14	24	30	6	13	2	10	28	16	Total
I	4	3	6	4	2	1	14	21	2	57
II	5	4	0	6	0	4	16	20	0	55
Average	4.5	3.5	3.0	5.0	1.0	2.5	15.0	20.5	1.0	56

TABLE 9.—*Time required for alfalfa seed to germinate on moistened filter paper without freezing.*

Plate No.	Dates when seeds were found to germinate										
	Jan.			Feb.			Mar.			Apr.	
	14	24	30	6	13	27	10	20	28	6	Total
I	6	5	4	4	0	4	0	18	13	2	56
II	9	2	3	0	4	6	2	15	17	2	60
Average	7.5	3.5	3.5	2.0	2.0	5.0	1.0	16.5	15.0	2.0	58

On examination of Tables 8 and 9 it is surprising to note the large total number germinating. It is regrettable that more seeds were not used so that the data could be more accurate. However, the data presented seem to indicate that alternate freezing and thawing (Tables 1 and 2) is no more effective in reducing the number of impermeable seed than when a similar sample of seed is kept for the same length of time in a moist condition.

Further examination of Tables 8 and 9 will show that a large number of seeds germinated about the middle of March. It appears that after remaining in a moist condition for the length of time indicated (65 days in the case of Table 8) many more of the seeds became permeable and germinated. It is also interesting to note that this larger number appeared about the same time in both tables and in consecutive order. Practically no seed germinated until it had been moistened for ten days. It is also noted that they germinated rather promiscuously, some weeks none germinating at all while at other times larger numbers germinated.

Upon further investigation of these tables it is seen that the seeds on the filter paper gave a higher total germination than those in soil. The thin covering of soil may have hindered or stopped the growth of the very weakest. This seems to indicate that the actual number that germinate or make their way through even a small layer of soil is slightly less than when they are germinated on filter paper.

In general the results seem to be contrary to the general idea that freezing and thawing greatly reduces the impermeability of alfalfa seed. However, freezing with the aid of water seems to expedite germination and causes a more uniform number to germinate each week.

RESULTS OF DODDER EXPERIMENTS

EFFECT OF ALTERNATE FREEZING AND THAWING

It has long been known that in dodder seed there is a very high percentage of impermeable seed and that the seeds will remain in the ground for many years and germinate a few each year. It was thought that by freezing and thawing these seeds would become permeable and germinate.

This experiment was started on November 16, 1925. Seven pans of 100 seeds each were used in the experiment. They were first placed in the germinating room for six days in order to find out the number that would germinate without freezing. The germinated seeds were picked out and counted, and the remaining seeds frozen one day of each week until April 15, when the experiment terminated. After freezing they were allowed to germinate for the remaining six days in each week. Table 10 gives the results that were obtained from alternate freezing and thawing of dodder seeds once each week for 20 weeks. The only dates recorded are those on which seeds germinated.

TABLE 10.—*Effect of alternate freezing and thawing on dodder seed.*

Pan No.	Number germinated before freezing	Dates when additional seeds germinated								Total germinated	Number dead	Total softened	Hard seed
		Nov.	Dec.		Jan.	Feb.	Mar.		Apr.				
		28	5	12	11	23	2	8	3				
A	5	0	0	1	1	0	0	2	0	9	7	16	84
B	6	0	1	0	0	1	0	0	0	8	9	17	83
C	5	1	1	1	0	1	0	1	0	10	8	18	82
D	3	2	1	1	0	0	0	1	0	8	13	21	79
E	2	1	0	3	0	0	1	0	0	7	12	19	81
F	4	0	0	2	1	0	1	0	0	8	6	14	86
G	3	0	0	0	0	1	0	2	1	7	10	17	83

The data presented in Table 10 indicate that freezing has very little, if any, influence on reducing the number of impermeable dodder seed, the greatest number germinating in any case being 10%, and the largest total number softened only 21%. This indicates a very high percentage of impermeable seed in dodder. The impermeable seeds are easily distinguished from the dead seed as the latter do not germinate but swell up with water and are later attacked by fungous growths if not removed.

EFFECT OF SCARIFICATION AND CONCENTRATED SULFURIC ACID ON ALFALFA AND DODDER SEEDS

Due to the large number of seeds that failed to germinate in the samples of seed used in the foregoing experiments, the question arises as to the viability of the sample used. To be sure that this lack of germination was due to the impermeability of the seed coats and also to test the viability of the seeds, scarification and treatment with concentrated sulfuric acid were used.

When the sample of impermeable alfalfa seed was treated for ten minutes in concentrated sulfuric acid, 85% of the seed germinated readily. The remaining seed germinated later when subjected to the same treatment for an additional five minutes. Usually 100% germination followed treatment for 20 minutes. When the original sample of alfalfa seed was scarificed once (2,800 revolutions per minute) 95% germinated

Samples of dodder were scarificed once and four times (2,800 revolutions per minute). With one scarification 16% germinated, and with four scarifications 25%. These results indicate either that the seed coat of dodder is not easily scarificed, or made permeable, or else the seed is not viable. However, when a similar sample of dodder was treated with sulfuric acid 70% germinated. The dodder seeds were treated with concentrated sulfuric acid for 15 minutes and then thoroughly washed and allowed to germinate for six days. The seeds that did not germinate were again treated for seven minutes, washed, and set to germinate. This method always resulted in the highest germination.

SUMMARY

1. Alfalfa seed contains a high percentage of impermeable seeds.
2. After the first freezing, subsequent freezing and thawing seem to have very little influence in reducing the number of impermeable alfalfa seeds.
3. The first freezing is by far the most effective. It reduced the number of impermeable seeds about 23%, on the average.
4. The intensity of freezing has no influence in reducing the impermeability. A temperature of 0°C. is fully as effective as —20°C.
5. When kept in a moist condition for several months as many seeds will germinate without freezing as a similar sample frozen each week during the same length of time. This would indicate that

freezing only expedites the process. The length of time the seeds are kept moist seems to be more important.

6. Alfalfa seed becomes permeable with age even when left in a dry condition. However, the rate is very slow when the seeds are stored at room temperature with little or no variation in temperature.

7. Freezing the seeds in a dry condition seems to be as effective as when the seeds are wet and frozen. This is especially true for the first freezing. It would seem from this that the warehouse that allows for seasonal changes in temperature would be beneficial in causing alfalfa seed to become permeable.

8. The duration of freezing seems to have no influence on germination. As many seeds became permeable and germinated after one hour of freezing as when a similar sample was frozen for 60 days.

9. The duration of thawing with subsequent freezing has very little influence in producing permeable seed, but it has a marked effect on the number of seeds that are killed. The longer the thaw, the greater the number of seeds that were killed with subsequent freezing. This strongly indicates that seeds which become permeable with one freezing are killed by the next.

10. The number of impermeable seeds in alfalfa varies according to the color of the seeds. The nearer the seeds approached the true color of bright yellow the more impermeable seeds were found. Green seed had a higher percentage of impermeable seeds than brown.

11. Alternate freezing and thawing has very little or no influence in reducing the number of impermeable dodder seeds. An average of only 8% germinated after 20 freezings, and of this number one-half germinated before freezing.

12. The alfalfa seed used in these experiments proved to be almost 100% viable when a test was made with sulfuric acid or scarification. The dodder seed used was found to be at least 70% viable with the sulfuric acid treatment.

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VISCOSITY AND WINTER HARDINESS IN THE SMALL GRAINS[1]

H. M. TYSDAL AND S. C. SALMON[2]

A recent study by the writers seems to confirm in an interesting way the colloidal theory of winter hardiness. Twelve varieties of wheat, a winter rye, and a winter barley, whose relative winter hardiness is known through tests conducted in various parts of the United States, were studied. The sap was expressed from the fresh, green, unfrozen leaves by means of a Lourie press capable of exerting a pressure of 1,000 atmospheres. The moisture content of the fresh tissue, the quantity of press juice, and the viscosity of the press juice were determined. These determinations were correlated with each other and with the air temperature to which the plants were exposed during the period immediately preceding the extraction of the sap.

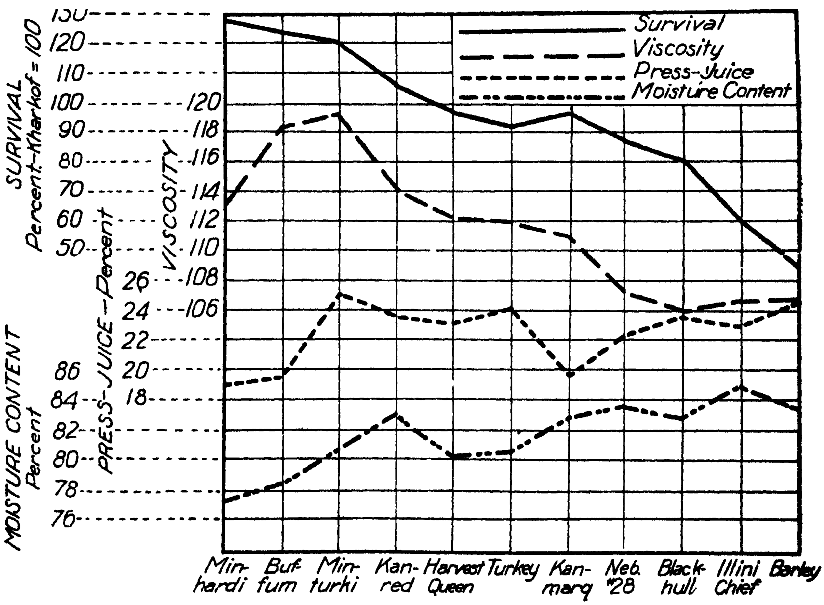

FIG. 1.

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[1] Contribution 163—Department of Agronomy, Kansas Agricultural Experiment Station. The present paper is an abstract of a thesis presented by the senior author in partial fulfilment of the requirements for the degree of master of science. Received for publication September 17, 1926.

[2] Graduate Assistant and Professor of Farm Crops, respectively.

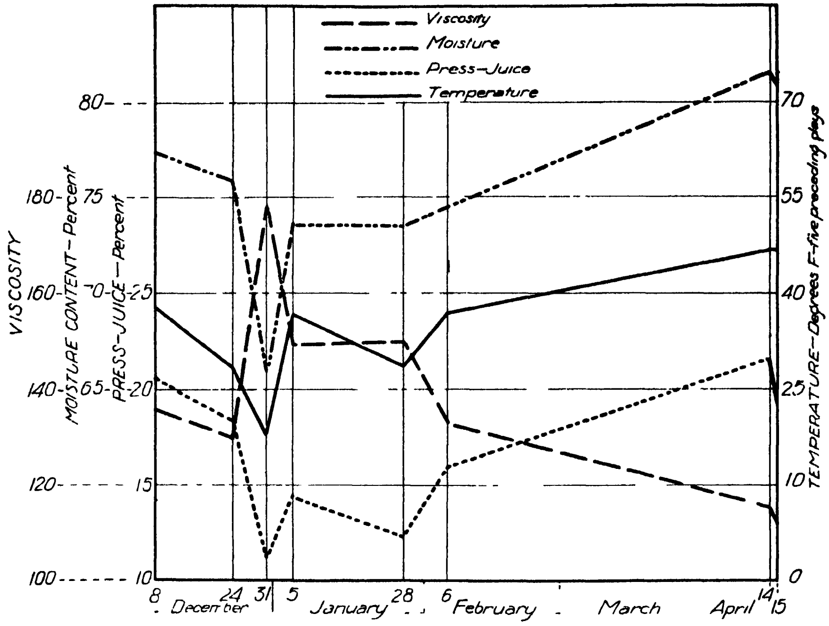

FIG. 2.

In the comparison of varieties a very high correlation was found between winter hardiness, on the one hand, and the moisture content of the tissue, quantity of press juice, and viscosity of the press juice on the other. This is illustrated in Fig. 1. The correlation coefficient between winter hardiness and moisture content of the tissue was found to be —.7950 ± .0766; between winter hardiness and quantity of press juice, —.4735 ± .1617; and between winter hardiness and viscosity of press juice, .8330 ± .0623. The numbers involved in the calculations were small, but nevertheless the results are such as to leave little doubt as to a definite relation between the factors studied.

Rye was collected at various times during the winter and early spring for similar determinations. A close correlation was found in this case between the temperature immediately preceding the determination and the moisture content of the tissue; also between temperature and press juice and between temperature and viscosity of the press juice. This is illustrated in Fig. 2.

A study was also made of the relation of viscosity and quantity of press juice and the temperature for various periods before the determinations were made. Very little correlation was found between the temperature 10 days or more before the determinations and the factors mentioned. In general the correlation was high for periods of six days or less.

CHLORATES AS PLANT POISONS[1]

(A preliminary report)

ALFRED ÅSLANDER[2]

Many attempts have been made to secure a reliable plant poison for the destruction of noxious vegetation. Arsenite of soda and common salt seem to be the most generally used. Unfortunately, the use of either of these substances in amounts necessary to obtain the desired effect leaves the soil bare of all vegetation for a long time. For that reason they can be used only on non-arable land or for the killing of single plants. A good plant poison for use on arable land has not yet been described.

The perennial weeds on arable land cause great damage by suppressing the growth of crops and increasing the cost of tillage. A reliable method for their eradication by means of some plant poison would be of considerable importance. Such a plant poison must have the following properties: (1) It must be effective even in relatively small quantities; (2) it must in some way be decomposed or absorbed in the soil so that crops can be grown soon afterwards; and (3) it must be composed of elements which are common enough to insure an inexpensive production even if its consumption greatly increases.

The writer has found that the use of chlorates, which are recommended by several writers as weed killers for tennis courts, garden paths, etc., has given promising results in eradicating Canada thistle (*Cirsium arvense* L.). An experiment was started at Ithaca, New York, in the autumn of 1925. Two permanent grass lands with a good growth of grasses and several weeds, among which *Cirsium arvense* was the dominating one, were selected for the experiment. Plats 4 square meters in area were laid out. The number of thistle shoots were counted on each plat. The following solutions were used as herbicides: Sodium chlorate, 10%; potassium chlorate, 6.5% (saturated solution); and sodium arsenite, 2%.

The solutions were sprayed on the plats in amounts corresponding to 107, 161, 214, 268, and 321 gallons per acre equivalent to 1,000, 1,500, 2,000 2,500, and 3,000 liters per hectare (10,000 square meters), respectively. The spraying was performed on November 11, after frost had killed the tops of the vegetation. The largest amount of the sprays was also applied to an extra plat from which later on were taken samles of roots for study of the effect of the poisons on them. It was found that the epidermis and the cortex were the first parts to be affected.

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[1] Contribution from the Department of Botany, Cornell University, Ithaca, N. Y. Received for publication September 29, 1926.

[2] International Education Board Fellow.

In the spring of 1926, it was very noticeable that the chlorates had been very effective. The plats to which the larger amounts had been applied were almost, or entirely, free from thistle shoots. Moreover, grasses and several other plants were injured much less or not at all, indicating that chlorates are selective plant poisons. The growth of annual weeds on the plats seemed to indicate that the poisonous action of the applied chemicals was only of a short duration.

On June 26 the thistle shoots on the plats were counted. On one of the experimental fields they were harvested and weighed. Table 1 gives the results obtained.

TABLE 1.—*Effect of sodium chlorate and sodium arsenite on Cirsium arvense L.*

Treatment, Nov. 11, 1925	Number of thistle shoots on 4 sq. meter plats, Oct. 21, 1925	Number of thistle shoots on 4 sq. meter plats, June 26, 1926	Green weight of thistle shoots on 4 sq. meter plats, June 26, 1926 Grams
Check	41	42	2,670
Sodium chlorate			
107 gallons per acre	41	5	74
161 gallons per acre	39	3	26
214 gallons per acre	43	3	3
268 gallons per acre	50	0	0
321 gallons per acre	49	0	0
Sodium arsenite			
107 gallons per acre	48	55	1,025
161 gallons per acre	39	35	1,675
214 gallons per acre	44	36	590
268 gallons per acre	51	52	1,750
321 gallons per acre	36	32	1,290

The data show that the largest amounts of sodium chlorate applied in autumn completely eradicated the thistles and that only a rather small amount was needed to obtain a decided reduction in their number and vitality. The effect of sodium arsenite in the amounts used and applied in autumn was much less. The effect of potassium chlorate was similar to that of sodium chlorate.

The results of the experiments thus seem to indicate that this is a promising method of dealing with at least some perennial weeds without interfering with the crops. Further experiments are in progress.

AVAILABILITY OF TENNESSEE RAW ROCK PHOSPHATE IN RELATION TO FINENESS AND OTHER FACTORS[1]

S. D. CONNER AND J. E. ADAMS[2]

Apparently very little work has been done on the relative availability of raw phosphate of different degrees of fineness. Jordan[3] made separations of raw ground Florida rock by means of sieves and bolting cloth and reported that the fineness of division had an important influence upon the availability of the raw phosphate.

DeTurk and Sears[4] report results of tests of raw phosphates of three degrees of fineness, showing negative results on the first two crops.

This investigation was started in 1921 for the purpose of obtaining more information on the effect of degree of fineness upon the availability of raw rock phosphate.

The experiment was conducted in galvanized iron pots painted on the inside with acid-resisting black asphalt paint. Duplicate series of pots were filled with Bedford silt loam, a slightly acid, light-colored soil from the Bedford experiment field.[5] This soil had been found to be notably deficient in phosphorus in a long series of field tests. Another series of duplicate pots were filled with a phosphorus-deficient Carrington silt loam, a slightly acid, dark soil from Benton County. One application of phosphates was made and the pots were cropped with small red forcing radishes, black bearded winter barley, Burr Leaming corn, and winter wheat. Each pot contained about 15 kilos of soil, kept at about 50% water-holding capacity with tap water. Lime was applied only in pot No. 11 in each series; however, the tap water used for watering contained some lime. The 1.4 grams of P_2O_5 applied to each pot was equivalent to approximately 1,400 pounds of 16% acid phosphate or 800 pounds per acre of 28% raw rock phosphate.

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[1] Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. Received for publication October 30, 1926.

[2] Research Chemist, Purdue University Agricultural Experiment Station, and formerly a graduate student, now Graduate Assistant in Chemistry, Iowa State College, Ames, Iowa, respectively. The portion of this work which was done by Mr. Adams was submitted as a thesis in partial fulfilment of the requirements for the degree of master of science at Purdue University.

[3] JORDAN, W. H. Influence of fineness upon the availability of raw ground phosphates. N. Y. Agr. Exp. Sta. Bul. 358. 1913.

[4] 37th Ann. Rpt. Ill. Agr. Exp. Sta., 16. 1924.

[5] Purdue Univ. Agr. Exp. Sta. Bul. 210. 1922.

TABLE 1.—*Treatment of pots.*

Pot No.	Treatment[a]
1	N, K
2	N, K, mono-calcium phosphate
3	N, K, di-calcium phosphate
4	N, K, raw rock phosphate
5	N, K, raw rock phosphate reground in ball mill
6	N, K, raw rock phosphate (fine sand separate)
7	N, K, raw rock phosphate (very fine sand separate)
8	N, K, raw rock phosphate (silt separate)
9	N, K, raw rock phosphate (clay separate)
10	N, K, raw rock phosphate + 5 grams sulfur per pot
11	N, K, raw rock phosphate + 50 grams $CaCO_3$ per pot

[a] N, K = 2 grams KNO_3 per pot.

All phosphate applications supplied 1.4 grams P_2O_5 per pot.

All pots received an additional application of 1 gram ammonium nitrate on barley and on wheat.

One gram per pot is equivalent to about 160 pounds per acre.

The Tennessee brown raw rock phosphate was used in the commercial fine ground form. Portions were also reground in a ball mill for ten hours.

TABLE 2.—*Mechanical analysis of raw rock phosphates.*

Separates	Size	Commercial rock	Reground rock
	mm.	%	%
Coarse sand	0.5 –1.0	0.4	0.0
Medium sand	0.25 –0.5	2.2	0.0
Fine sand	0.10 –0.25	19.3	0.1
Very fine sand	0.05 –0.10	21.5	0.4
Silt	0.005–0.05	29.6	23.9
Clay	0.000–0.005	26.8	75.5

The method used in making the mechanical separation was that employed by the U. S. Bureau of Soils and described in Bulletin 84 of that Bureau. A compound microscope with a calibrated eye-piece was used to check the size of the separates. The four finer separates were used in the experiments. The results are given in Table 2. Each separate was analyzed as was also the original phosphate, so that equivalent amounts of phosphorus could be applied to each pot.

TABLE 3.—*Chemical analyses of phosphates and separates.*

Separates	P_2O_5	CaO
	%	%
Mono-calcium phosphate	56.0	22.0
Di-calcium phosphate	40.0	32.0
Tennessee rock phosphate	27.9	39.7
Fine sand separate	36.4	47.5
Very fine sand separate	33.4	45.9
Silt separate	27.7	42.2
Clay separate	21.2	25.4

The reground raw phosphate was of the same composition as the commercial phosphate. It may be seen from the analyses given in Table 3 that the mechanical separates varied in chemical composition, the coarser separates being composed of purer calcium phosphate than the finer separates. This brown Tennessee phosphate is a decomposed phosphatic lime stone with more or less extensive infiltrations of clay and silt from the over-lying soil. In preparing this rock phosphate commercially, much of this clay is washed out but not all. In making the mechanical separation, there is more clay left in the finer separates. If such a separation were made of a pulverized phosphate prepared from a hard rock phosphate, it is probable that there would not be such a great difference of phosphorus in the separates. For this reason, the results obtained in this experiment do not apply to hard rock phosphate.

TABLE 4.—*Average yields of crops on Bedford silt loam in grams total plants per pot.*[a]

Pot No.	Radishes	Barley	Corn	Wheat	Total 4 crops	Percentage increase mono-calcium phosphate 100%
1	11.3	19.1	21.0	54.7	106.1	——
2	88.3	63.2	41.0	58.4	250.9	100.0
3	83.5	53.9	42.5	62.0	241.9	93.8
4	63.0	34.0	33.0	61.0	191.0	58.0
5	65.8	43.4	33.3	59.2	201.7	66.0
6	45.6	29.2	24.5	61.0	160.3	37.4
7	55.5	34.5	22.5	62.6	175.1	47.6
8	51.0	37.3	30.0	56.9	175.2	47.7
9	66.1	41.5	29.0	58.9	195.5	61.7
10	38.6	41.5	26.0	57.0	163.1	39.3
11	25.6	12.8	25.2	69.0	132.6	18.3

[a] Barley, corn, and wheat, dry weights; radishes, green weights.

TABLE 5.—*Average yields of crops on Carrington silt loam in grams total plants per pot.*[a]

Pot No.	Radishes	Barley	Corn	Wheat	Total 4 crops	Percentage increase mono-calcium phosphate 100%	Average percentage increase two soils
1	28.9	56.7	35.7	71.1	192.4	——	——
2	79.8	70.1	63.3	77.2	290.4	100.0	100.0
3	74.8	65.6	54.0	77.9	272.3	81.5	87.7
4	47.2	63.0	43.3	70.4	223.9	32.1	45.1
5	56.3	57.8	45.3	71.8	231.2	39.6	52.8
6	50.0	59.6	43.7	77.1	230.4	38.8	38.1
7	56.9	57.8	42.5	72.5	229.7	38.1	42.9
8	47.9	62.0	40.0	77.2	227.1	35.4	41.6
9	57.8	58.7	49.0	75.8	241.3	50.0	55.9
10	53.1	69.3	48.0	76.7	247.1	55.8	47.6
11	30.1	47.1	44.0	79.4	200.6	8.3	13.3

[a] Barley, corn, and wheat, dry weights; radishes, green weights.

Tables 4 and 5 give the average results in the duplicate pots with radishes, barley, corn, and wheat on two types of soil. The phosphates were all thoroughly mixed with the entire amount of soil. For this reason the raw phosphate might show a higher relative crop-producing value than it would in short time experiments in the field.

The commercial raw rock phosphate gave approximately one-half the crop increase that the mono-calcium and di-calcium phosphates gave.

Regrinding the rock phosphate increased its crop-producing value about 8%, which is hardly sufficient to justify cost of regrinding.

The finest separate, which was of the mechanical grade of clay, had a somewhat higher value than the reground phosphate. The three coarser separates were of lower value than the commercial rock.

On the Bedford silt loam, sulfur caused a depression in the crop-producing value of the raw phosphate. On the Carrington silt loam, sulfur gave a definite increase. Limestone used in addition to the raw phosphate was depressing in its action on both soils.

After the wheat crop was removed, the soils were sampled and analyzed for available phosphoric acid, using fifth-normal nitric acid at room temperature. Table 6 shows the percentage of dilute acid soluble phosphoric acid remaining in the soil of the differently treated pots, and the pounds per acre of such phosphoric acid in excess of that in the untreated soil.

TABLE 6.—*Phosphoric acid soluble in fifth-normal nitric acid in each soil.*[a]

	Bedford silt loam		Carrington silt loam	
Pot No.	Percentage in soil	Excess due to treatment, pounds per acre	Percentage in soil	Excess due to treatment, pounds per acre
1	0.0021	—	0.0025	—
2	0.0032	22	0.0047	44
3	0.0034	26	0.0051	52
4	0.0056	70	0.0087	124
5	0.0050	58	0.0080	110
6	0.0056	70	0.0082	114
7	0.0056	70	0.0076	102
8	0.0057	72	0.0076	102
9	0.0047	52	0.0076	102

[a] There were approximately 224 pounds phosphoric acid per acre applied per pot.

The Carrington silt loam soil, where the smaller crop increases were obtained, had the largest residue of dilute acid soluble phosphorus remaining. In both soils the mono-calcium and di-calcium phosphates which gave the greatest crop increases left smaller residues of phosphorus than were left from the raw phosphate. While there still remained relatively large supplies of phosphorus soluble in dilute acid in the soils treated with raw rock phosphate, the crop yields do not indicate that it is available to plants in the same proportion in which it is soluble in dilute acid. The dilute acid evidently dissolves the calcium phosphate of the larger as well as the smaller particles of rock phosphate about as completely as it does chemically precipitated phosphate.

SUMMARY

Commercial fine ground raw Tennessee phosphate was compared in pot cultures with the same material reground in a ball mill.

The reground phosphate was only 7.7% more effective than the commercial phosphate.

The finest mechanical separate in the phosphate (clay) was 10% more effective than the commercial phosphate.

The pot tests on these two phosphorus hungry soils do not indicate that it would pay to grind such phosphate finer for use as fertilizer in the raw form.

The relative effectiveness of the phosphates tested was as follows: Mono-calcium phosphate, 100; di-calcium phosphate, 87.7; commercial raw ground phosphate, 45.1; reground commercial raw phosphate, 52.8.

The addition of sulfur to the raw phosphate gave an increase on one soil and a decrease on the other soil.

Carbonate of lime reduced the availability of the raw phosphate on both soils.

NITROGEN AND SULFUR IN RAINWATER IN NEW YORK[1]

Benjamin D. Wilson[2]

For a number of years the rainwater at Ithaca, New York, has been collected and analyzed monthly and semi-annually for nitrogen and sulfur respectively. Reports (3, 4)[3] of this work with rather extended bibliographies have appeared in the literature.

It is the purpose of the present paper to bring together the data which are now available for Ithaca and also those for two other collecting stations, one located at Brockport, New York, and one at Alfred, New York.[4] The rainfall from these last two stations was analyzed for sulfur semi-annually. Nitrogen was determined for periods so arranged that certain of them included the collections for one-half of the year beginning with May, while other collections covered the remaining portion of the year.

At each of these stations the precipitation was collected in an 8-inch gauge. After each rain or snow its contents was emptied and the water stored, until analyzed, in a glass bottle containing a few drops of a saturated solution of mercuric chloride. The samples of rainwater were analyzed for ammoniacal nitrogen by the Nessler reaction as used in water analysis and for nitrate nitrogen by the phenoldisulfonic-acid method. Sulfur was determined by evaporating 1-liter samples of the filtered water, both with and without the addition of an oxidizing agent. The sulfur, all of which was found to be in the form of sulfate, was finally weighed as $BaSO_4$

NITROGEN IN RAINWATER AT ITHACA

The gauge used for collecting the rainfall at Ithaca is located in a cultivated field and stands about 9 feet from the ground. In a previous paper (3) it is stated that this field is in an area comparatively free from smoke. Since then a large heating plant has been constructed within a mile of the field. While its operation, since the fall of 1923, has increased materially the smoke in the vicinity of the gauge, it has not caused the nitrogen in the rainwater to be consistently higher than that found in years prior to its construction.

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[1] Contribution from the Department of Agronomy. Cornell University, Ithaca, N. Y. Received for publication October 30, 1926.

[2] Assistant Professor of Soil Technology.

[3] Reference by number is to "Literature Cited," p. 1112.

[4] The writer wishes to acknowledge the hearty cooperation of Prof. C. O. Beaman of the State Normal School, Brockport, N. Y., and of Dean J. N. Norwood of Alfred College, Alfred, N. Y., who sent to this laboratory, for several years, rainwater collected at their respective residences.

Table 1 shows the nitrogen content of the rain falling at Ithaca for 11 years. Its variation from year to year is striking. While its nitrogen content for the first three years appears to be extremely high in the light of the more recent values, it is not in excess of that reported by Freeman (1) for certain localities in Kentucky. No attempt will be made to explain this variability in the nitrogen content. It is of such magnitude that an average figure for the values shown would be misleading. For this reason no averages have been tabulated. It may be seen from the table under discussion that the precipitation contains each year a much larger quantity of nitrogen in the form of ammonia than in the form of nitrate.

TABLE 1.—*Nitrogen in the rainwater at Ithaca, May, 1915, to May, 1926.*

Period collected	Rainfall in inches	N as NH_3 in pounds per acre	N as NO_3 in pounds per acre	Total N in pounds per acre
1915–1916	30.3	16.3	0.8	17.1
1916–1917	25.4	16.9	1.0	17.9
1917–1918	36.5	16.1	1.6	17.7
1918–1919	30.3	3.3	0.8	4.1
1919–1920	24.0	2.5	0.9	3.4
1920–1921	25.1	4.7	0.6	5.3
1921–1922	31.8	4.0	1.1	5.1
1922–1923	31.5	1.6	0.7	2.3
1923–1924	24.4	4.0	0.6	4.6
1924–1925	29.8	1.5	0.2	1.7
1925–1926	35.0	7.6	0.6	8.2

NITROGEN IN THE RAINFALL AT BROCKPORT AND ALFRED

The gauges used for collecting the precipitation at Brockport and Alfred, both of which are villages, were located in the residential sections. Brockport lies 20 miles west of Rochester, New York. Its topography is rather level with an elevation of about 500 feet. Alfred, with an altitude of approximately 1,700 feet, is situated 10

TABLE 2.—*Nitrogen in the rainwater at Brockport, May, 1923, to May, 1926.*

Period collected	Rainfall in inches	N as NH_3 in pounds per acre	N as NO_3 in pounds per acre	Total N in pounds per acre
1923–1924	30.2	1.3	0.3	1.6
1924–1925	29.3	1.5	0.0	1.5
1925–1926	35.7	5.0	0.4	5.4

TABLE 3.—*Nitrogen in the rainwater at Alfred, May, 1923, to May, 1925.*

Period collected	Rainfall in inches	N as NH_3 in pounds per acre	N as NO_3 in pounds per acre	Total N in pounds per acre
1923–1924	29.2	10.5	0.4	10.9
1924–1925	35.6	15.0	0.1	15.1

miles southwest of Hornell, New York. It lies in a narrow valley running north and south. The hills, both to the east and to the west, rise abruptly, and within a mile of the village attain an elevation several hundred feet greater than that of the valley. The nitrogen content of the rainwater falling at these stations is shown in Tables 2 and 3. At Alfred the nitrogen content was found to be much higher than at Brockport, but in both instances practically all of the nitrogen was in the form of ammonia.

SULFUR IN RAINWATER

At Ithaca the rainfall has been analyzed for sulfur for a period of eight years, the results of which are given in Table 4. It may be seen that the concentration of sulfur for five successive years, beginning with May, 1918, was less than that shown for the period following May, 1923. For these two periods, however, the concentration was more or less constant. The heating plant, which was put into operation in the fall of 1923, was responsible, no doubt, for the higher concentration of sulfur in the rainfall subsequent to that date. Since the concentration of sulfur was rather uniform for the two periods mentioned above, the amount brought down in the rainfall was dependent, in large measure, on the annual precipitation.

The concentration and the total quantity of sulfur in the rainwater at Brockport and Alfred are shown in Tables 5 and 6. There was little yearly variation in the concentration of sulfur in the rain-

TABLE 4.—*Sulfur in the rainwater at Ithaca, May, 1918, to May, 1926.*

Period collected	Rainfall in inches	Sulfur in p.p.m.	Sulfur in pounds per acre
1918–1919	30.3	4.1	27.8
1919–1920	24.0	4.5	24.6
1920–1921	25.1	4.6	26.0
1921–1922	31.8	4.6	33.4
1922–1923	31.5	5.0	35.9
1923–1924	24.4	8.3	45.8
1924–1925	29.8	7.0	47.4
1925–1926	35.0	8.2	65.1

TABLE 5.—*Sulfur in the rainwater at Brockport, May, 1923, to May, 1926.*

Period collected	Rainfall in inches	Sulfur in p.p.m.	Sulfur in pounds per acre
1923–1924	30.2	11.8	80.5
1924–1925	29.3	10.1	67.2
1925–1926	35.7	10.5	84.9

TABLE 6.—*Sulfur in the rainwater at Alfred, May, 1923, to May, 1925.*

Period collected	Rainfall in inches	Sulfur in p.p.m.	Sulfur in pounds per acre
1923–1924	29.2	7.6	50.4
1924–1925	35.6	6.1	49.1

TABLE 7.—*Sulfur in the rainwater at Ithaca, Brockport, and Alfred for half-year periods, May, 1922, to May, 1926.*

Period collected	Ithaca			Brockport			Alfred		
	Rainfall in inches	Sulfur in p.p.m.	Sulfur in pounds per acre	Rainfall in inches	Sulfur in p.p.m.	Sulfur in pounds per acre	Rainfall in inches	Sulfur in p.p.m.	Sulfur in pounds per acre
May, 1922, to Nov., 1922	23.9	2.7	14.7	—	—	—	—	—	—
Nov., 1922, to May, 1923	7.6	12.3	21.2	—	—	—	—	—	—
May, 1923, to Nov., 1923	15.1	3.9	13.3	13.1	4.9	14.6	15.7	2.9	10.3
Nov., 1923, to May, 1924	9.3	15.5	32.5	17.1	17.0	65.9	13.5	13.1	40.1
May, 1924, to Nov., 1924	20.5	3.4	13.0	17.4	4.5	17.8	22.9	2.6	13.5
Nov., 1924, to May, 1925	9.3	16.4	34.4	11.9	18.3	49.4	12.7	12.4	35.6
May, 1925, to Nov., 1925	24.1	3.6	16.7	21.5	3.9	18.7	—	—	—
Nov., 1925, to May, 1926	10.9	19.6	48.4	14.2	20.6	66.2	12.0	14.2	38.4

water at these two stations. The concentration, however, was found to be much higher at Brockport.

It is during the winter months that the rainfall contains its greatest amount of sulfur. It may be seen from Table 7 that the half-year periods which include the winter months, or that portion of the year when large quantities of coal are being consumed, contain much larger amounts of sulfur than do the half-year periods which include the summer months. This is true for all of the stations shown. There appears to be a direct relationship between the concentration of sulfur in the rainfall and the quantity of smoke in the atmosphere. The effect of the heating plant, already referred to, was to increase greatly the concentration of sulfur in the precipitation at Ithaca during the winter season. This may be seen from a comparison of the sulfur concentration in the water for the period between November, 1922, and May, 1923, with the values shown for the other corresponding periods. This relationship does not seem to exist for nitrogen at Ithaca, since the quantity of this element in the precipitation was not consistently increased with the construction of the heating plant. However, Shutt (2) found the nitrogen in the precipitation at Ottawa, Canada, to be increased with the more extensive use of bituminous and semi-bituminous coal in that city.

CONCLUSIONS

The nitrogen content of rainwater, most of which was present in the form of ammonia, was found to vary at different collecting stations. It also varied from year to year at the same station. While the sulfur content varied at different stations, its concentration remained rather uniform at any one station. Thus, the quantity of sulfur brought down yearly in the rain was dependent, to a marked degree, on the annual precipitation. The rainwater contained its greatest concentration of sulfur during the winter months.

Certain details in connection with the presence of nitrogen and sulfur in rainwater have been discussed in previous papers from this laboratory. A restatement of them will not be made.

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SEMINAL ROOT DEVELOPMENT IN CORN IN RELATION TO VIGOR OF EARLY GROWTH AND YIELD OF CROP[1]

L. H. SMITH AND E. H. WALWORTH[2]

Much effort has been expended in the study of seed corn with respect to various external characters of ear and kernel in the search for whatever may assist in predicting the relative productiveness of a seed ear.

The development of seminal or temporary roots in the germinating plantlet of corn, as well as of other grains, represents a variable characteristic which can be observed and compared, with the advantage that the fluctuations with respect to the number of rootlets are more definite than the characters usually observed involving shape, size, or color, where the gradations are continuous. The question is suggested as to whether there is any relation between the development of these seminal rootlets and the productivity of the plant. Does a greater number of these seedling rootlets represent an endowment whereby the young plant is given a more vigorous start in life which results finally in higher yielding capacity? It is the purpose to present, herewith, some results of observations and experiments bearing upon this problem.

The work of this investigation was taken up under three divisions as follows: (1) A study of the variability in the production of seminal rootlets; (2) observations on the early growth of plants from seed ears high and low in seminal root development; and (3) comparison by field test of the productiveness of seed ears high and low in seminal root development.

In attacking this problem it was first necessary to learn of the manner in which development of seminal rootlets varies.

Wiggans[3] has published the results of his observations in seminal rootlets in corn as well as in some of the small grains, and the present writers[4] have published similar data with respect to wheat, oats, and barley.

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[1] Contribution from the Division of Plant Breeding, Department of Agronomy, University of Illinois Agricultural Experiment Station, Urbana, Illinois. Published with the approval of the Director. Received for publication October 30, 1926.

[2] Formerly Chief in Plant Breeding, now in charge of publications of the Soil Survey, and formerly First Assistant in Crop Production, now Agricultural Adviser, Macon County, Ill., respectively.

[3] WIGGANS, ROY G. The number of temporary roots in cereals. *In* Jour. Amer. Soc. Agron., 8:31–37. 1916.

[4] WALWORTH, E. H., and SMITH, L. H. Variations in the development of secondary rootlets in cereals. *In* Jour. Amer. Soc. Agron., 10:32–35. 1918.

Numerous previous observations had taught us what was brought out in Wiggans' data, namely, that there is great variation in the number of seminal roots arising from different germinating kernels of a single ear; also that different individual ears display characteristic tendencies in this regard.

In order to become better acquainted, however, with the manner of variation and its limits, a systematic and rather extensive test was planned in which altogether about 450 individual ears taken from eight different dent varieties were examined.

A liberal number of grains from each ear were germinated. At first, 176 kernels were taken, but after a study of the data it was decided that a smaller sample would suffice and so in the subsequent work 90 to 100 kernels were used as the ear sample.

It may be explained here that in counting the number of seminal roots in this investigation the radicle was not included for the reason that in normal germination the radicle is always present, and therefore is not involved in the variation. Since the radicle is often referred to as the "primary" seminal root, then by analogy the other seminal roots are "secondary." Strictly speaking, therefore, the data involve the secondary seminal, or temporary, roots.

The results were recorded in form of distribution tables showing for each ear the number of kernels producing 0 rootlets, 1 rootlet, 2 rootlets, and so on up to 10 rootlets, which was the maximum number found. The mean number of rootlets for the ear was also determined. On account of the space required to show these tables, the detailed results are not presented here. The data, however, are very similar to those already shown by Wiggans in the article referred to above and they confirm his findings concerning variation among kernels and among ears.

The data showing a comparison of varieties are given in Table 1. The results in the column for "mean number of rootlets" are derived by averaging for the different individual ears of the respective varieties the mean number of rootlets produced by the sample kernels; that is to say, the figures are averages of averages. The table shows a noticeable difference among varieties in their tendencies, the mean number ranging from 3.08 in Reid Yellow Dent to 3.55 in Western Plowman. The table indicates further greater variability in some varieties than in others if "standard deviation" be accepted as the index of variability. According to these results Reid Yellow Dent is most variable with a standard deviation of 0.55, while Boone County White was most uniform with the standard deviation at 0.36.

TABLE 1.—*Average number of secondary seminal roots found in different varieties of corn and the Standard Deviations corresponding thereto.*

Variety	Mean number rootlets	Standard deviation
Reid Yellow Dent	3.08±.04	0.55±.03
Riley's Favorite	3.22±.04	0.46±.03
Champion White Pearl	3.33±.04	0.46±.03
Leaming	3.29±.04	0.48±.03
Silvermine	3.38±.04	0.41±.03
Boone County White	3.18±.03	0.36±.02
Golden Eagle	3.40±.04	0.45±.03
Western Plowman	3.55±.05	0.51±.03

This portion of the study leads to the following conclusions regarding the variability in the development of seminal rootlets in corn: (1) Kernels of an individual ear show a wide range of variation; (2) individual ears possess characteristic tendencies in this respect; and (3) varieties show small characteristic differences.

VIGOR OF EARLY GROWTH IN RELATION TO SEMINAL ROOT PRODUCTION

From the records of the extensive individual ear observations described above there were selected for comparison of vigor of juvenile growth two groups of 15 ears each, one group having a relatively high tendency in seminal root development and the other a low tendency. For the high group no ears were taken in which the average number of seminal roots per seedling was less than four and for the low group none were taken whose average was above three, the general averages for the two groups being 4.32 and 2.43, respectively.

A 35-kernel sample from each of these ears was planted in a sand flat in the greenhouse. The unfolding of successive leaves in the young plantlets was taken as a measure of the juvenile growth, and daily counts were made in which the number of plantlets were recorded as the first, second, third, fourth, and fifth leaves made their appearance.

The first leaves started to emerge on the sixth day from planting and records for first leaves were made on the sixth and seventh days. Second leaves began to show on the seventh day and records for the unfolding of second leaves were made on the seventh, eighth, and ninth days. Similarly, emergence of third leaves was recorded during the four-day period from the ninth to twelfth day, fourth leaves from the thirteenth to the twenty-second day, and fifth leaves from the nineteenth to the twenty-fourth day.

These records are summarized in Table 2. The figures given represent the average number of leaves per plant observed on the

TABLE 2.—*Time of first appearance of successive leaves in plantlets of relatively high and low tendencies in seminal root development.*

Results reduced to average number of leaves per plant observed on respective days.

Days after planting	First leaf High[a]	First leaf Low[b]	Second leaf High	Second leaf Low	Third leaf High	Third leaf Low	Fourth leaf High	Fourth leaf Low	Fifth leaf High	Fifth leaf Low
6	0.36	0.41								
7	0.83	0.88	0.14	0.16						
8			0.37	0.38						
9			0.83	0.84	0.04	0.03				
10					0.31	0.25				
11					0.72	0.66				
12					0.87	0.84				
13							0.15	0.04		
14							0.37	0.14		
15							0.48	0.20		
16							0.60	0.28		
17							0.68	0.38		
18							0.73	0.47		
19							0.83	0.56	0.02	0.01
20							0.88	0.67	0.04	0.01
21							0.92	0.76	0.07	0.03
22							0.95	0.84	0.11	0.04
23									0.14	0.06
24									0.25	0.08

[a] General average number of seminal roots per plant 4.32.

[b] General average number of seminal roots per plant 2.43.

respective days and they are arranged in such manner as to show the relative progress in development of the two kinds of corn according to the tendency in seminal root production.

The data show no significant differences in the earliest stages of development. At about the thirteenth day, however, there appears to be a slight, though consistent, tendency for the progenies of ears of high seminal root production to forge ahead of those of the low group. This behavior is brought out perhaps more clearly by the graphic representation in Fig. 1.

As a further test of the relative vigor of early growth, the weights of the plants produced in these cultures were compared. After taking the records on leaf development as described above, the plantlets were all pulled up, cleaned, dried, and weighed. The average weight per plant for each ear-progeny is given in Table 3.

The general averages, without further analysis, might be taken to indicate a larger growth from the seed of high seminal root production, but upon calculating the correlation coefficient a value of $\gamma = 0.17 \pm .12$ is found, a result considered as not statistically significant.

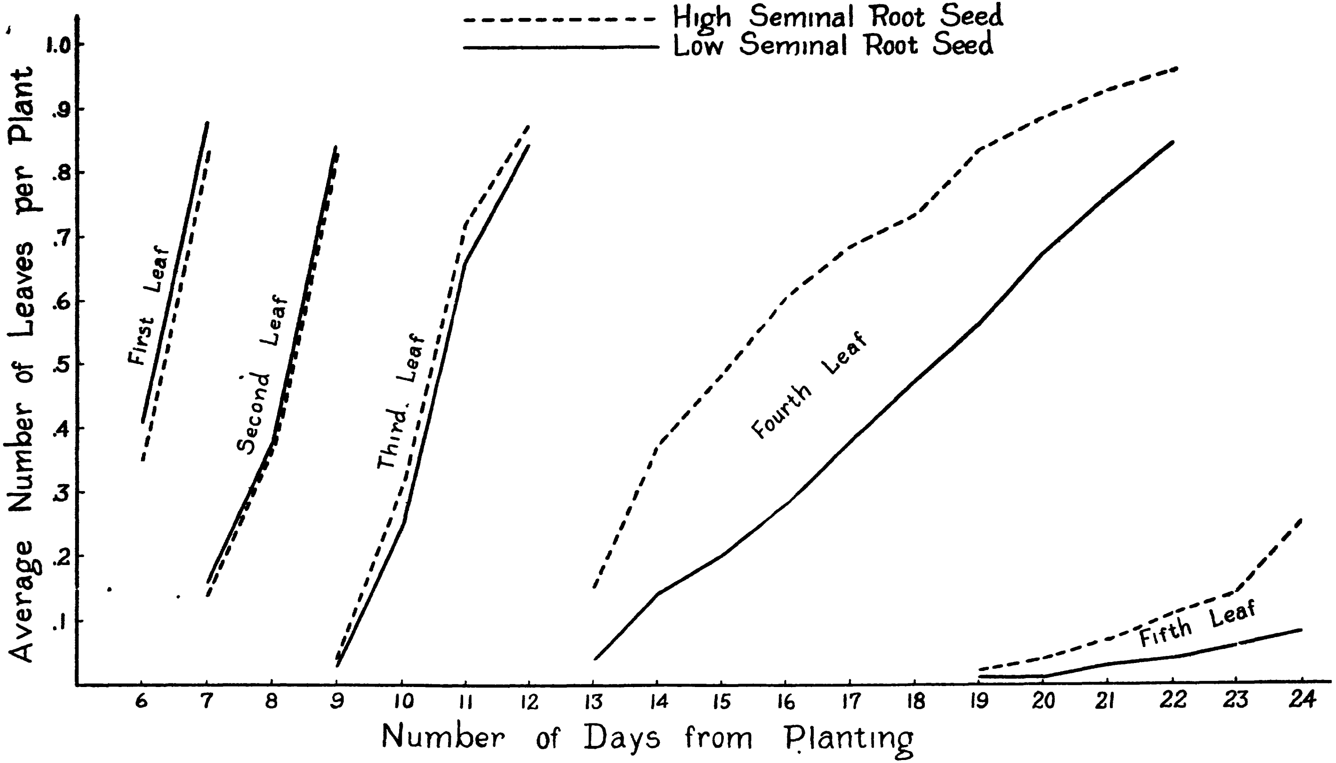

FIG. 1.—Comparative growth of plantlets of relatively high and low tendencies in seminal root development, as indicated by the time of unfolding of successive leaves.

The results on this phase of the study, therefore, do not establish very positive conclusions, although the observations on leaf development seem to indicate a slight relationship between seminal root development and vigor of early growth. At least the evidence appears sufficient to provoke further investigation.

TABLE 3.—*Relative weight of plantlets grown from parent ears of high and low seminal root tendencies.*

Ear record No.	Average number seminal roots produced in seedlings from parent ear		Average weight per plant of ear-progenies in grams	
52	4.21		52.8	
33		2.14		57.9
55	4.12		55.0	
9		2.21		62.5
69	4.26		57.6	
20		2.17		61.1
71	4.12		67.5	
72		2.36		57.6
97	4.82		62.6	
85		2.41		51.7
21 G	4.71		60.4	
6		2.18		53.5
33 G	4.60		81.7	
17 A		2.29		44.5
40 G	4.40		69.8	
32 A		2.36		71.2
3 A	4.08		67.5	
20 C		2.72		42.1
23 C	4.41		60.3	
45 C		2.73		55.5
31 F	4.35		74.3	
4 F		2.47		49.8
42 F	4.19		61.7	
29 F		2.58		64.3
25 B	4.14		92.2	
24 B		2.62		81.2
5 D	4.04		85.7	
43 D		2.64		87.9
40 B	4.40		50.1	
22 D		2.56		87.7
Average	4.32	2.43	66.6	61.9

Correlation coefficient $(\gamma) = .17 \pm .12$

RELATIVE YIELDING CAPACITY OF EARS OF HIGH AND LOW SEMINAL ROOT TENDENCIES

The same two lots of ears used in the early growth experiments described above were subjected to a comparative yield test in the field.

The seed was planted in the manner of the ordinary individual ear-row test, the rows being repeated in duplicate series. The results are presented in Table 4 in terms of pounds of ear corn per row. The yield of the individual rows are given separately and the average of the two series for each progeny is shown in the last two columns of the table. The general average of the crop from mother ears of high seminal root production was 29.9 pounds per row, while that for the ears of low seminal root production was 26.9 pounds. Calculating

TABLE 4.—*Relative yield of rows of corn from parent ears of high and low seminal root tendencies.*

Ear record No.	Average number seminal roots in seedlings from parent ear		Weight in pounds of corn produced in ear-row progenies					
			Series I		Series II		Average Series I and II	
52	4.21		31.3		25.8		28.6	
33		2.14		27.4		22.8		25.1
55	4.12		30.0		33.2		31.6	
9		2.21		22.5		20.7		21.6
69	4.26		33.0		34.6		33.8	
20		2.17		26.7		26.6		26.7
71	4.12		31.1		30.7		30.9	
72		2.36		22.7		24.8		23.8
97	4.82		21.9		27.6		24.8	
85		2.41		26.9		32.1		29.8
21 G	4.71		26.7		24.3		25.5	
6		2.18		26.1		29.0		27.6
33 G	4.60		28.3		31.5		29.9	
17 A		2.29		25.8		26.9		26.4
40 G	4.40		29.8		37.3		33.6	
32 A		2.36		24.7		32.5		28.6
3 A	4.08		25.0		32.6		28.8	
20 C		2.72		21.3		30.2		26.3
23 C	4.41		27.7		34.1		30.9	
45 C		2.73		24.8		32.8		28.8
31 F	4.35		26.1		31.2		28.7	
4 F		2.47		24.7		24.8		24.8
42 F	4.19		28.2		29.0		28.6	
29 F		2.58		23.7		26.3		25.0
25 B	4.14		29.1		30.6		29.9	
24 B		2.62		26.3		28.7		27.5
5 D	4.04		31.2		37.2		34.2	
43 D		2.64		26.0		20.2		23.1
40 B	4.40		28.8		28.9		28.9	
22 D		2.56		26.8		31.3		29.1
Average	4.32	2.43	28.5	25.1	31.2	27.3	29.9	26.9

Correlation coefficient (γ) = .50±.09

the correlation coefficient, we find, $\gamma = 0.50 \pm 09$, a value of considerable significance from the statistical standpoint.

This comparison of yields thus furnishes rather strong evidence in support of the idea that seminal root development may be taken to indicate in some degree the relative inherent productiveness of a seed ear.

It is recognized that the data at hand are rather limited upon which to base sweeping conclusions and the writers would in nowise overdraw the importance of these results unless confirmed by more extensive experiments. If, however, these results are substantiated by further investigation, the matter should be of considerable interest from the practical standpoint of seed selection. The counting of the seminal roots on the seedlings can easily be added to the other observations of the germination test as it is now commonly conducted. Some evidence is available indicating that 10 kernels from an ear would suffice as a fairly representative sample for this purpose, but this is a detail that ought also to receive further study.

SUMMARY

Observations on the development of the seminal roots in corn show that there is great variation in number of secondary seminal roots produced in different seedlings; that individual ears possess characteristic tendencies in this respect; and that varietal differences are also noticeable.

Data are presented showing a positive correlation between high seminal root production and yield of crop. There is also some evidence that high seminal root production tends to enhance vigor of early growth.

Based upon these findings it is suggested that the observation of seminal root production in connection with the germination test may furnish an additional item to the list of aids in selecting seed ears of higher productiveness.

FURTHER STUDIES OF THE POLLINATION OF ORCHARD GRASS[1]

T. K. Wolfe and M. S. Kipps[2]

The authors (10)[3] previously reported in this Journal some results secured with the pollination of orchard grass flowers. It was found that paper bags were more satisfactory for self-pollinating orchard grass flowers than cotton cages. However, only one cotton cage was used. During 1926 the experiments of 1925 were repeated in order to secure a greater amount of data on the cotton cages. These results, together with data in reference to the influence of self-pollination on size of seed and the production of chlorophyll-deficient seedlings, are presented herewith.

MATERIAL AND METHODS

The method of producing self- and open-pollinated seed was the same as previously reported (10). Before weighing the seeds the lemnas and paleas were removed and only the caryopses were weighed The number of chlorophyll-deficient seedlings were obtained by planting the seed in flats of soil in the greenhouse and making counts every other day.

RESULTS AND DISCUSSION

EFFECT OF METHOD OF POLLINATION ON SET OF SEED

The results showing the number of seed produced from the different methods of pollination are presented in Table 1. The percentage of plump seed set when the flowers were open-pollinated ranged from 21.3 to 55.4; when close-pollinated, two heads enclosed in a paper bag, 0.3 to 37.3; when self-pollinated, one head enclosed in a paper bag, 0.9 to 21.6; and when self-pollinated by enclosing the entire plant in a cotton cage, 8.2 to 35.7. The average set of plump seed for the eight clonal lines when open-pollinated was 43.24%; when close-pollinated, 9.30%; when self-pollinated by use of the paper bag, 8.84%; and when self-pollinated by enclosing the entire plant in a cotton cage, 20.89%. Such results indicate that some clonal lines are more self-fertile than others. They also indicate, contrary to the results previously reported, that there is a greater set of plump seed when self-pollination was accomplished by the use of cotton cages

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[1] Contribution from the Department of Agronomy, Virginia Agricultural Experiment Station, Blacksburg, Virginia. Received for publication November 2, 1926.

[2] Agronomist and Assistant Agronomist, respectively.

[3] Reference by number is to "Literature Cited," p. 1127.

TABLE 1.—*Showing the results of the pollination of orchard grass flowers.*

Clon No.	Type of pollination	Number of heads studied	Plump seed	Number of Shrivelled seed	Sterile flowers	Percentage of flowers setting seed	
						Plump	Shrivelled
5	Open	3	569	269	382	46.6	22.0
	Single plant enclosed in cotton cage	3	228	194	754	19.4	16.5
	Single head enclosed in paper bag	2	11	310	808	1.0	27.5
	Two heads from same plant enclosed in paper bag	2	3	254	648	0.3	28.1
63	Open	3	399	33	318	53.2	4.4
	Single plant enclosed in cotton cage	3	451	95	952	30.1	6.3
	Single head enclosed in paper bag	2	282	432	1,043	16.1	24.6
	Two heads from same plant enclosed in paper bag	2	595	214	788	37.3	13.4
108	Open	3	860	124	1,014	43.0	6.2
	Single plant enclosed in cotton cage	3	212	149	1,149	14.0	9.9
	Single head enclosed in paper bag	2	55	724	1,054	3.0	39.5
	Two heads from same plant enclosed in paper bag	2	82	377	937	5.9	27.0
131	Open	3	178	139	154	37.8	29.5
	Single plant enclosed in cotton cage	3	232	115	841	19.5	9.7
	Single head enclosed in paper bag	2	85	696	823	5.3	43.4
	Two heads from same plant enclosed in paper bag	2	76	763	800	4.6	46.6
140	Open	3	599	80	402	55.4	7.4
	Single plant enclosed in cotton cage	3	480	179	1,387	23.5	8.7
	Single head enclosed in paper bag	2	545	14	2,177	19.9	0.5
	Two heads from same plant enclosed in paper bag	2	181	8	2,364	7.1	0.3
164	Open	3	392	38	481	43.0	4.2
	Single plant enclosed in cotton cage	3	100	353	763	8.2	29.0
	Single head enclosed in paper bag	2	47	750	848	2.9	45.6
	Two heads from same plant enclosed in paper bag	2	90	425	631	7.9	37.1
172	Open	3	152	244	316	21.3	34.3
	Single plant enclosed in cotton cage	3	296	152	1,321	16.7	8.6
	Single head enclosed in paper bag	2	25	8	2,757	0.9	0.3
	Two heads from same plant enclosed in paper bag	2	149	1,106	1,811	4.9	36.1
230	Open	3	518	58	561	45.6	5.1
	Single plant enclosed in cotton cage	3	619	90	1,024	35.7	5.2
	Single head enclosed in paper bag	2	297	209	867	21.6	15.2
	Two heads from same plant enclosed in paper bag	2	87	344	932	6.4	25.2

than by the use of paper bags. The cotton cages are more convenient to handle than the paper bags, require less work and attention, and the set of seed is not so likely to be interfered with by rain and moisture. In case of rain, after the heads are bagged, many of the bags catch water and hold it and the pollination of the flowers is hindered. The temperature inside the cotton cage is greater than the outside air and in all probability higher than that inside of the paper bags, but this factor has not seemed to be a serious drawback. The results reported in this paper should be more reliable than those previously reported (10) as a larger number of cotton cages and bags were used.

EFFECT OF POLLINATION ON SIZE OF SEED

The results presented in Table 2 show the effect of pollination on the size of orchard grass seed. In all cases except 192 D and 192 E seed produced by open-pollination weighed more than seed produced from either close- or self-pollination. In seven instances the self-pollinated seed were larger than the close-pollinated seed when paper bags were used to effect the pollination. In the other eight cases the reverse was true. In two of the three instances where the production of self-pollinated seed by the use of the cotton cage is comparable to the production of this kind of seed by means of paper bags, the seed produced in the cotton cage is larger, but in the remaining case the reverse is true.

The calculation of the average weight of the seeds from the different methods of pollination shows the average weight per hundred in milligrams of the open-pollinated seed to be 70.8; self-pollinated in paper bags, 59.4; and close-pollinated, 58.0. In case of clonal lines 131, 140, and 172, where self-pollination by means of the cotton cage was included, the average weight per hundred in milligrams of the open-pollinated seed was 86.9; self-pollinated in cotton cage, 64.4; self-pollinated in paper bags, 64.1; and close-pollinated, 73.0. Such results indicate that the open-pollinated seed are the largest and there is practically no difference in the weight of self- and close-pollinated seeds. It is probable that some of the differences in size may be attributed to the artificial method of production of the self- and close-pollinated seeds. Undoubtedly, however, some of the differences may be attributed to the method of pollination. It has been frequently shown that cross-pollinated corn kernels are larger than self- or close-pollinated kernels when they are all produced on the same ear.

TABLE 2.—*Showing the weight of seeds (caryopses) of orchard grass as influenced by different methods of pollination.*

Clon No.	Type of pollination	Number of seeds	Weight of 100 seeds, mgm.
157B	Open	109	80.0
	Single head enclosed in paper bag	19	64.2
	Several heads from same plant enclosed in paper bag	44	84.5
173C	Open	80	93.5
	Single head enclosed in paper bag	128	54.9
	Several heads from same plant enclosed in paper bag	95	74.0
175D	Open	47	55.5
	Single head enclosed in paper bag	68	54.7
	Several heads from same plant enclosed in paper bag	48	30.6
176E	Open	759	70.5
	Single head enclosed in paper bag	70	68.6
	Several heads from same plant enclosed in paper bag	105	54.5
176F	Open	394	67.8
	Single head enclosed in paper bag	50	44.4
	Several heads from same plant enclosed in paper bag	262	66.8
178C	Open	165	51.3
	Single head enclosed in paper bag	74	33.0
	Several heads from same plant enclosed in paper bag	149	38.4
178G	Open	69	65.5
	Single head enclosed in paper bag	97	45.6
	Several heads from same plant enclosed in paper bag	220	46.9
192B	Open	286	77.0
	Single head enclosed in paper bag	25	64.4
	Several heads from same plant enclosed in paper bag	10	60.0
192D	Open	31	63.5
	Single head enclosed in paper bag	17	84.1
	Several heads from same plant enclosed in paper bag	14	65.7
192E	Open	29	49.3
	Single head enclosed in paper bag	19	75.3
	Several heads from same plant enclosed in paper bag	8	27.5
227F	Open	34	50.6
	Single head enclosed in paper bag	16	45.0
	Several heads from same plant enclosed in paper bag	12	30.8
254F	Open	1,173	77.3
	Single head enclosed in paper bag	53	64.9
	Several heads from same plant enclosed in paper bag	163	71.9
131	Open	126	112.3
	Single plant enclosed in cotton cage	180	92.3
	Single head enclosed in paper bag	35	81.4
	Two heads from same plant enclosed in paper bag	99	98.9
140	Open	205	66.1
	Single plant enclosed in cotton cage	120	53.0
	Single head enclosed in paper bag	302	66.0
	Two heads from same plant enclosed in paper bag	153	56.9
172	Open	55	82.4
	Single plant enclosed in cotton cage	74	48.0
	Single head enclosed in paper bag	20	45.0
	Two heads from same plant enclosed in paper bag	18	63.3

EFFECT OF SELF-POLLINATION ON THE OCCURRENCE OF CHLOROPHYLL-DEFICIENT SEEDLINGS

The results reported in Table 3 show that chlorophyll-deficient seedlings occur in some instances when orchard grass seed is produced as the result of self-pollination. There was some variation between different clonal lines as to the number of etiolated seedlings produced. Clons 5, 140, and 230 did not show any such seedlings, but all of the remainder did. Clon 63 contained the largest number of chlorophyll-deficient seedlings and clon 108 the second highest. In all cases the self-pollinated seeds showed the highest percentage of etiolated seedlings. Some of the open-pollinated seed produced such seedlings, and it is possible that some of the supposedly open-pollinated seed were self-pollinated.

It is generally assumed that the occurrence of chlorophyll-deficient seedlings is convincing evidence that self-pollination has taken place. The occurrence of chlorophyll-deficient seedlings has been reported for self-pollinated lines of timothy by Hayes and Barker (2); for corn by Hutchison (4), Jones (5), Lindstrom (7, 8), and Hayes and Barker (2); and for red clover by Fergus (1) and Kirk (6).

Just what effect self-pollination will have on the vigor of orchard grass remains to be seen. However, it is a logical method for eliminating undesirable types of orchard grass and for securing vigorous,

TABLE 3.—*The occurrence of chlorophyll-deficient seedlings of orchard grass produced from open-pollinated and self-pollinated seeds.*

Clon No.	Type of pollination	Number of seedlings	Number of chlorophyll-deficient seedlings
	Open	2,400	0
5	Single plant enclosed in cotton cage	948	0
	Single head enclosed in paper bag	158	0
	Open	1,294	18
63	Single plant enclosed in cotton cage	3,279	107
	Single head enclosed in paper bag	215	5
	Open	2,641	1
108	Single plant enclosed in cotton cage	465	7
	Single head enclosed in paper bag	73	2
	Open	5,921	1
131	Single plant enclosed in cotton cage	968	0
	Single head enclosed in paper bag	54	1
	Open	1,372	0
140	Single plant enclosed in cotton cage	568	0
	Single head enclosed in paper bag	83	0
	Open	1,732	0
164	Single plant enclosed in cotton cage	303	0
	Single head enclosed in paper bag	105	2
	Open	2,649	1
172	Single plant enclosed in cotton cage	1,057	1
	Single head enclosed in paper bag	6	0
	Open	5,280	0
230	Single plant enclosed in cotton cage	2,280	0
	Single head enclosed in paper bag	155	0

hardy sorts. Kirk (6) working with red clover and Jones (5) with corn found self-pollination greatly reduced the vigor. On the other hand, Hayes and Clarke (3) and McRostie (9) found that timothy is not greatly reduced in vigor by self-pollination. If the better types of orchard grass obtained through self-pollination compare favorably with commercial seed, as is true with timothy, the production of new and improved strains for distribution to farmers will be greatly aided. At any rate self-pollination tends to discard some of the weaker types as shown by the appearance of chlorophyll-deficient seedlings.

SUMMARY

Some clonal lines of orchard grass set a higher percentage of seed than others. Some are more self-fertile than others, but the production of self-pollinated seed should be, as a whole, fairly easily accomplished.

Contrary to results previously reported by the authors (10) cotton cages were more satisfactory for self-pollinating orchard grass flowers than paper bags. The results presented in this paper should be of more significance as a greater amount of data is used than in the previous paper. It is believed that the cotton cages will prove more convenient and satisfactory to handle than the paper bags.

The percentage of flowers setting plump seeds when they were open-pollinated ranged from 21.3 to 55.4; when close-pollinated, 0.3 to 37.3; when self-pollinated by enclosing one head in a paper bag, 0.9 to 21.6; and when self-pollinated by enclosing a single plant in a cotton cage, 8.2 to 35.7. The average percentage of seed set when open-pollinated was 43.24; when close-pollinated, 9.30; when self-pollinated by enclosing one head in a paper bag, 8.84; and when self-pollinated by enclosing a single plant in a cotton cage, 20.89.

Open-pollinated seed weighed more than either close- or self-pollinated seed. There was practically no difference in the weight of seed when close- or self-pollinated.

Some clonal lines when self-pollinated produced more chlorophyll-deficient seeds than others. A higher percentage of chlorophyll-deficient seedlings was produced when the seed were self-pollinated than when open-pollinated. The occurrence of etiolated seedlings when the seed were open-pollinated is in all probability the result of a certain amount of self-pollination taking place under field conditions. It is generally assumed that the occurrence of chlorophyll-deficient seedlings is convincing evidence of self-pollination.

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COMPARATIVE VALUE OF SCARIFIED AND OF UNHULLED SEED OF BIENNIAL WHITE SWEET CLOVER FOR HAY PRODUCTION[1]

T. K. Wolfe and M. S. Kipps[2]

Sweet clover is rapidly increasing in importance in many sections of the country. The general recommendation is to use scarified seed if best results are to be secured. Certain farmers in Virginia have obtained better returns from unscarified than from scarified seed. Tests were started in 1925 by the Virginia station to study the comparative value of scarified and unhulled sweet clover seed for hay production. Some striking results were secured and they are presented in this paper.

MATERIAL AND METHODS

Seedings were made with unhulled seed at the rate of 35 pounds per acre and scarified seed at the rate of 20 pounds per acre on the following dates: August 1, August 15, September 1, October 15, November 15, December 15, January 15, February 15, March 1, March 15, April 1, and April 15. Germination tests were conducted in the laboratory before the experiment was started. It was assumed

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[1] Contribution from the Department of Agronomy, Virginia Agricultural Experiment Station, Blacksburg, Va. Received for publication November 2, 1926.

[2] Agronomist and Assistant Agronomist, respectively.

that all the hard seed would germinate after they were planted in the soil. The rates of seeding were adjusted so as to give 20 and 35 pounds of scarified and unhulled seed, respectively, on the basis of hard seed plus seed which germinated in the laboratory. The seedings were made on Hagerstown silt loam soil which would produce, on the average, about 50 bushels of corn per acre. The clover was seeded alone on August 1, August 15, and September 1, while it was seeded on wheat on the other dates.

RESULTS AND DISCUSSION

The results presented in Table 1 show that unhulled seed gave higher yields in every instance than scarified. It is interesting to note such results from the late summer and late spring as well as the winter and early spring seedings. The first three dates of seeding are not comparable to the other dates as they represent two crops of hay and the others one; also they were at a disadvantage on account of unusually dry weather during the summer of 1925. The results for the first three dates are given to show the comparative value of unhulled and scarified seed under the existing conditions. The average yield from the scarified seed was 281 pounds and from the unhulled, 1,253 pounds of hay per acre.

TABLE 1.—*The number of plants and yields per acre produced from scarified and unhulled biennial white sweet clover seeds sown on different dates at Blacksburg, Va.*

Date of seeding	Scarified		Unhulled	
	Number of plants	Yield in pounds	Number of plants	Yield in pounds
Aug. 1, 1925	117,612	145	757,944	1,485
Aug. 15, 1925	91,476	195	457,380	1,015
Sept. 1, 1925	95,832	85	579,348	935
Oct. 15, 1925	43,560	0	261,360	795
Nov. 15, 1925	17,424	0	300,564	1,170
Dec. 15, 1925	43,560	140	836,352	1,400
Jan. 15, 1926	52,272	95	496,584	1,045
Feb. 15, 1926	165,528	810	1,672,704	1,985
Mar. 1, 1926	439,956	785	1,611,720	1,835
Mar. 15, 1926	527,076	365	1,851,300	1,595
Apr. 1, 1926	365,904	335	182,952	1,450
Apr. 15, 1926[a]	0	0	0	0

[a] The season was extremely dry and no stands resulted.

A study of the data in Table 1 in reference to the number of plants per acre show that there was a much larger number of plants in the case of the unhulled seed. There is an exception in case of the April 1 seeding, but even then the unhulled seed gave a larger yield than the scarified.

Results such as reported here are not confined to sweet clover. It is common knowledge that unhulled crimson clover usually gives better stands and yields than hulled seed. It would be interesting and of practical value to determine why the unhulled seed gives better results than scarified. An experiment is being started to study this problem. It will also be worth while to determine the comparative value of unhulled, scarified, and hulled but not scarified sweet clover seed. This study is being made at the present time.

SUMMARY

The results indicate that unhulled biennial white sweet clover seed are superior from the standpoint of hay production to scarified seed. One season is too short a time for a test of this kind to give conclusive results but the consistency of the results lends weight to them. These results are presented with the hope that other agronomists will conduct tests to determine the comparative value of unhulled, scarified, and hulled but not scarified sweet clover seed for hay production

NOTE

A SUCCESSFUL APPLICATION OF THE SYSTEM OF ROOT-CUTTING TO THE HARVESTING OF GRAIN SORGHUM

After the recent paper[1] outlining a system of "Root Cutting as an Aid in Harvesting Grain Sorghums with a Combine" had been prepared and sent forward for publication, an example of the successful use of the proposed system in actual farm practice came to the writer's attention. A note concerning this observation was sent to the Editor of the JOURNAL for addition to the original article as a footnote, but reached him too late to be used in this way. It is, therefore, presented here as an interesting confirmation of the feasibility of the proposed method.

A farmer from the Winters District near Davis, while visiting the University Farm in the fall of 1925, was shown over our root-cutting experiments by the field foreman. After harvesting with the one-row header about half of his 40 acres of Double Dwarf Milo which he had planted in rows 3½ feet apart and putting the heads in low windrows to dry, he became worried about the prospects of rain damaging the heads so placed.

After experimenting a few days, he evolved a one-row, horse-drawn cutter, similar to one suggested by the writer except that a sled type was used instead of the wheeled type the writer had in mind. The frame of wood was arched to go over the row of sorghum. No eveners were used but a chain with a single tree at the end was attached to each side of the cutter and a steady team of mules (each under 1,500 pounds) used to pull it. A thin sharp blade supported from the sled runners accomplished the cutting. The teamster rode the back end of the cutter to force the blade far enough into the ground.

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[1] This JOURNAL, 18:729-742. 1926.

With this outfit, the second half of the Milo crop was given the root cutting. After allowing the plants to dry out following the root cutting the crop was successfully threshed with a combine. Several plants which were missed in the threshing remained standing through the rains of winter with but slight deterioration of the grain until the tract was plowed in the spring.

During this present season, this farmer and two friends, who became interested in his success with this method of harvest, have leased and planted to the Double Dwarf Milo about 1,700 acres of land between Davis and Sacramento. They have used the alternate 7- and 3½-foot row spacings suggested by the writer and now being used at the University Farm. This has enabled them to do all of their work so far, including planting and cultivation, with large tractors at a minimum expense. The writer learned of this farmer's past experience and present undertakings for the first time soon after July 1, 1926.—JOHN P. CONRAD, *Research Assistant, Division of Agronomy, University of California, Davis, Calif.*

FELLOWS ELECT, 1926

In assembling and presenting the accompanying sketches, the Executive Committee is indebted to the following members of the Society for their helpful cooperation: Messrs. P. E. Brown, C. M. Woodworth, J. G. Lipman, L. E. Call, L. E. Thatcher, and W. L. Burlison.—L. H. SMITH, *for the Executive Committee.*

BURT LAWS HARTWELL

Burt Laws Hartwell has been for many years Director of the Rhode Island Agricultural Experiment Station. The substantial character of his scientific training is evidenced by the possession of a bachelor's degree from Boston University (1889), a master's from the Massachusetts Agricultural College (1900), and a doctor's from the University of Pennsylvania (1903).

Doctor Hartwell's professional career was begun at the Massachusetts Experiment Station where he served as assistant chemist from 1889 to 1891. He then became first assistant chemist of the Rhode Island Station (1891–1903), and later associate chemist (1903–1907), chief chemist (1907–), director (1912–), agronomist (1913–) and professor of agricultural chemistry (1908–). An honored member of several scientific societies, a faithful servant in the field of agricultural science, a loyal friend, Doctor Hartwell has won for himself the confidence and respect of colleagues in his field.

The American Society of Agronomy owes much to his wise judgment. He is the representative of the Society on the Council of the American Association for the Advancement of Science. The members of the Society feel honored in giving recognition to him for his valuable contributions on plant physiology and soil fertility.

HARRY HOUSER LOVE

Harry Houser Love has been Professor of Plant Breeding at Cornell University since 1911. He began his official career as Assistant Chemist in the Illinois Agricultural Experiment Station is 1904, the title being changed the following year to Assistant in Plant Breeding. In 1907 he took a similar position at Cornell, advancing two years later to Assistant Professor of Plant Breeding. For many years he has been a collaborator of the United States Department of Agriculture. Last year he spent several months in China in the interest of plant breeding work in that country.

For his scientific training he attended Illinois Wesleyan, graduating in 1904. He pursued postgraduate study at the same institution, at the University of Illinois, and at Cornell where he received the Ph.D. degree in 1909.

Among Doctor Love's accomplishments may be mentioned the introduction into New York State of several improved strains of wheat and oats. At the time, he has made valuable scientific contributions to the genetics of the small grain crops. He has given especial attention to the application of statistical analysis to the problems of agronomy and there is no doubt that his work in this field has stimulated a general interest in this matter which has resulted in promoting the worth of agronomy work throughout the country.

Doctor Love has been a member of the American Society of Agronomy since 1908 with the exception of one year. He has served the Society on the following important committees: Committee on Varietal Standardization, Committee on the Standardization of Field Experiments, and Sub-committee on the Registration of Wheat Varieties.

CHARLES ANSEL MOOERS

Charles Ansel Mooers is Director of the Agricultural Experiment Station and Professor of Agronomy of the University of Tennessee. His official service at that institution dates from his graduation in 1893 when he became assistant chemist. With the exception of one year spent as chemist at the North Louisiana Experiment Station, his connection with the Tennessee Agricultural Experiment Station has been continuous.

Director Mooers was born in Maine, and reared on a farm. He graduated from the University of Tennessee with a bachelor's degree in 1893. He is one of an honored group of broadly trained agronomists who entered the profession through the field of chemistry. During his long period of service both as chemist and agronomist, he has made many worthy contributions to science in both fields of work.

Director Mooer's connection with the American Society of Agronomy dates from its origin. He has served the Society effectively in many important capacities. He was associate editor for Crop Production of the JOURNAL for several years. He served on the Soil Classification and Mapping committee, and also the Committee on Standardization of Field Experiments. In 1921 he was President of the Society.

EMIL TRUOG

Emil Truog was born and reared on a farm at Independence, Wisconsin. He graduated from the University of Wisconsin in 1909 and received the M. S. degree from the same institution in 1912.

His first appointment was that of Assistant in Soils on the staff of the University of Wisconsin in 1909 from which position he was advanced to Instructor, Assistant Professor, Associate Professor and Professor of Soils, which title he now holds.

Professor Truog has made numerous contributions to scientific journals and farm papers, presenting the results of his thorough and painstaking studies of numerous soils problems. He has been especially interested in soil acidity and has developed several methods for testing soils for acidity, which have been very widely used. He has also investigated the availability of phosphorus, the feeding power of plants, soil colloids and numerous other problems connected with the scientific and practical study of soils. Professor Truog is a recognized authority on soils subjects.

In the Agronomy Society, Professor Truog has been a frequent contributor to the program and in 1924 he arranged a symposium on Soil Colloids. In 1923 he served as a Vice-President of the Society.

CARLOS GRANT WILLIAMS

Carlos Grant Williams is the present Director of the Ohio Agricultural Experiment Station. Born in Ohio, reared on an Ohio farm, and with a life devoted to the improvement of farming, it is not surprising that the name of Williams has become identified with agricultural development in that state.

Director Williams was made Chief of the Agronomy Department in the Ohio Station in 1903 and in 1921 he became Director. He served two years (1914–15) as a member of the Ohio Agricultural Commission. For many years he has been a contributing editor to the Ohio Farmer through which medium his influence on agricultural practice has been widely spread. In the earlier years of his investigational work he gave special attention to field crops and their improvement through the methods of plant breeding. The well known variety of Trumbull wheat may be mentioned as a single example, among others, of a valuable product of this line of effort. In later years he has widened his field of interest to comprehend the whole subject of agronomy, including both soils and crops, and many valuable contributions to agronomic literature might be mentioned.

Director Williams has been a faithful member of the American Society of Agronomy since its beginning, and during the past year he has borne the honors and responsibilities of President of the organization.

AGRONOMIC AFFAIRS

MINUTES OF THE NINETEENTH ANNUAL MEETING

MORNING SESSION, THURSDAY, NOVEMBER 18

The meeting was called to order at 9:30 A. M. by the President, Director C. G. Williams, at the Willard Hotel, Washington, D. C. More than 200 were registered and considerably more than 250 were present at the various sessions.

The following special committees were appointed: *Nominating*, C. R. Ball, H. L. Walster, and C. A. Mooers. *Auditing*, W. W. Burr, E. P. Deatrick, and George Roberts. *Resolutions*, R. W. Thatcher, Andrew Boss, and B. L. Hartwell. A special committee consisting of T. L. Lyon and C. A. Mooers was appointed to confer with a committee from the American Soil Survey Association to consider the desirability of listing the membership of the American Society of Agronomy in two groups—Soils and Crops—so that the Soils group with the Soil Survey Association might serve as the sponsoring agency for the International Congress of Soil Science to be held in Washington next year.

The following program was given:

1. "Corn Borer Research in Ohio"
    L. L. Huber, Department of Entomology, Ohio Agricultural Experiment Station
    R. M. Salter, Department of Agronomy, Ohio Agricultural Experiment Station
    Discussion opened by J. F. Cox, Michigan State College
2. "Economics of Permanent Pasture Improvement"
    J. W. White, Department of Agronomy, Pennsylvania State College
    Discussion
3. "The Present Status of Legume Inoculation"
    A. L. Whiting, Department of Agricultural Bacteriology, University of Wisconsin
    Discussion
4. "The Present Status of Soil Investigations in the Field"
    C. F. Marbut, Bureau of Soils, U. S. Dept. of Agriculture

AFTERNOON SESSION, THURSDAY, NOVEMBER 18

SYMPOSIUM—"PUBLICATION OF RESULTS OF AGRONOMIC RESEARCH"

Leader: R. W. Thatcher, Director, New York State Agricultural Experiment Station.

1. "Should the Results of Agronomic Research be Published in Bulletins, or in Scientific Journals, or Both?"
    R. W. Thatcher, Director, New York State Agricultural Experiment Station
2. "The Technical Bulletin as a Writer Sees It"
    C. R. Ball, Bureau of Plant Industry, U. S. Dept. of Agriculture
3. "Characteristics of a Good Journal Article"
    M. C. Merrill, Editorial Chief of Publications, U. S. Dept. of Agriculture

4. "Methods of Graphic Representation of Experimental Data"
   J. D. Luckett, Editor, New York State Agricultural Experiment Station
5. "Making Photographs for Illustration in Published Articles"
   C. H. Hanson, Specialist Visual Instruction, U. S. Dept. of Agriculture
6. "Popular Presentation of the Results of Agronomic Research"
   J. F. Cox, Department of Agronomy, Michigan State College

Discussion

EVENING SESSION, THURSDAY, NOVEMBER 18

The annual dinner of the Society was held at the Hotel Hamilton at 6:30 P. M. About 130 were present.

At the conclusion of the dinner Director C. G. Williams, President of the Society, delivered an address entitled "What Can Agronomists Contribute to the Solution of the Agricultural Problem?"

The annual business meeting of the Society was then held.

OFFICERS' REPORTS

R. W. Thatcher, Editor, presented his report which was accepted.

REPORT OF THE EDITOR

The Editor has the pleasure to report that the past year has been, in his opinion, the most successful one in the history of the JOURNAL. More worthy articles have been contributed for publication by members of the Society; more pages of printed matter have appeared; more copies of the JOURNAL have been mailed to members and subscribers; the income from advertising has been greater; and the net cost per page has been less; than in any previous year. That the JOURNAL of our Society is rapidly becoming recognized as one of the leading scientific publications of this country and probably the leading agronomic journal of the world is indicated by the rapidly increasing arrival of unsolicited subscriptions from libraries and scientists all over the world. These circumstances are real cause for congratulation to the Society.

The very considerable increase in volume of material to be handled is, of course, an increasing burden upon the officers of the Society who give their voluntary service to the publication of the JOURNAL. The details of preparing manuscripts for the printer, proof-reading, dealing with authors concerning proofs, arrangements for make up, etc., are most efficiently handled by the Assistant Editor and Advertising Manager, whose services in these matters are gratefully acknowledged by the Editor. But the mere matter of receiving, examining, and accepting or rejecting manuscripts is now becoming one which requires large expenditures of time and energy. Scarcely a single manuscript arrives which does not require correspondence with the author as to editorial revision, inquiry for information which has been omitted in submitting the paper, etc. The exercise of the function of acceptance or rejection of articles for publication requires considerable care in examination and evaluation of each paper for the particular purposes which are to be served by our JOURNAL. With a total of 160 manuscripts arriving during the year, this work is getting to be almost more than one man can do in addition to other duties which are supposed to occupy his full time and attention. In former years, there were a considerable number of associate and assistant editors, to whom it was theoretically intended that part of the responsibility for the editorial services mentioned above should be assigned. When the present Editor assumed the duties of the office, he at first tried to share the editorial services and responsibilities with the corps of associate and assistant editors. But he soon found that the delay in getting action on manuscripts which were sent through the mails to others for consideration interfered seriously with prompt publication. But worse still, from his standpoint, the additional correspondence with the associate editors and with authors concerning points raised by the former became more than he could devote to this part of the work. Hence, either rightly or wrongly, the whole system of voluntary associate and assistant editorships was abandoned and the employment of a paid assistant editor and advertising manager adopted instead. The latter part of the plan has worked out most satisfactorily and will probably continue to do so, so long as the two officers are located at the same institution and in the city where the JOURNAL is published.

In the event that either of these officers should remove from his present location, the present arrangement would not proceed so satisfactorily. And in any event, if the volume of manuscripts which must receive editorial consideration should materially increase in the future, it is probable that some plan for additional editorial service will have to be devised.

Turning now from the personal troubles of the Editor to the situation with respect to the JOURNAL itself, there seems to be ample reason for satisfaction in the progress which has been made during the year.

The November issue, which has just come from the press, closes on page 1056. The material which is now in process of preparation for the December issue will occupy 120 or more additional pages. Hence, Volume 18 of the JOURNAL will consist of just a little less than 1,200 pages of text matter, exclusive of advertising inserts, title pages, table of contents, etc. Volume 17 contained 846 pages; Volume 16, 824 pages; Volume 15, 538 pages; and Volume 14, 377 pages. The current volume will, therefore, contain 40% more pages than any preceding one and will be more than three times the size of the JOURNAL as it was five years ago.

It seems to be the general concensus of opinion, at least so far as the Editor has been able to ascertain this, that this gain in *quantity* of material published has been accomplished without any serious loss in *quality;* and that, hence, it represents the real increase in contributions to knowledge of agronomic science and practice by members of the Society, through its JOURNAL. Other avenues of publication are used by the agronomists of this country for the presentation of some of the results of their researches and investigations, so that the sum total of such contributions to knowledge by American agronomists is now a very large one.

It might be interesting to note at this point that, aside from certain invitation papers presented at symposium programs, in only two cases during the past year has the rule that papers will be accepted for publication in the JOURNAL only from members of the Society been deviated from. Hence, the JOURNAL represents almost exclusively contributions to knowledge by members of the American Society of Agronomy.

For the sake of brevity and also because it would show no essentially new conditions, the list of institutions from which contributions came during the past year is omitted from this report.

There were received by the Editor a total of 159 manuscripts, classified as follows: Symposium papers, 41; contributed articles, 90; committee reports, 5;

book reviews, 11; and notes, 12. This is an increase of 19 papers over the number received last year. Such an increase in number would not account for a 40% increase in number of pages printed. Hence, it must be that this year's papers averaged somewhat longer than those of preceding years.

Of the 159 papers received, 129 were published in the first eleven issues of Volume 18, 13 were returned to their authors for one reason or another, 15 have been turned over to the Assistant Editor for preparation for use in the December issue; leaving only 2 in the hands of the Editor for later publication at the time when this report was written. No manuscript which was received prior to November 1 will be unpublished at the end of the year.

No contributed article has been delayed in publication more than four months and most of them have appeared in print within three months after they were received by the Editor. To accomplish this prompt publication of contributed papers, it has been necessary to hold some of the papers presented as parts of the several symposia at the last annual meeting until as late as the October issue of this year. This is, of course, not altogether satisfactory to the authors of the symposium papers which are treated in this way. It is the opinion of the Editor, however, that it would not be fair to the authors of contributed papers which usually contain the results of original investigations which it is desired to make public as promptly as possible, to hold such papers until all of those that are presented at the annual meeting symposium programs have been published. The policy of devoting alternate issues of the JOURNAL to symposia papers and to contributed articles has been followed for the past two years because of this opinion on the part of the Editor and not because of any authorization or expression of opinion from the Society or its Executive Committee. If any change in this policy is desired by the members of the Society, the Editor gladly will be guided by their wishes in the matter.

The opening of the pages of the JOURNAL to the new type of articles known as "Notes" seems to have served a useful purpose. Twelve such "Notes" will be published in Volume 18. They serve to make available to other agronomists observations or opinions which may have come to their writers through other channels than those of the experimental study which is the required basis for scientific contributions; but which may not be less valuable to others by reason of this difference in origin. The Editor will be glad to see even more frequent use made of the opportunity to publish these "Notes" in the future.

As in former years, great difficulty was experienced by the Editor in securing suitable "News Items" for publication in the JOURNAL. Local correspondents are again urged to greater attention to these matters. Also, if members of the Society who change their professional engagements during the year would give to the Editor a brief statement concerning the matter in addition to the customary notice of change of address (this latter sometimes coming from a postmaster instead of from the member himself), it would add to the interest of this part of the JOURNAL.

The cost of and income from publication of the first ten issues of Volume 18, as compared with similar data for preceding volumes, were as follows:

Vol. No.	No. of pages	Total cost	Advertising income	Reprints sold	Net cost	Cost per page
15	538	$3,221.56	$697.60	$294.62	$2,229.34	$4.13
16	824	4,392.79	783.97	500.40	3,106.40	3.77
17	846	4,538.19	734.65	462.03	3,341.65	3.95
18*	952	5,134.10	925.79	646.50	3,551.81	3.73

*10 issues

These data show that, by reason of a considerably increased income from advertising the net cost per page of the present volume is the lowest that it has ever been The increase in number of pages will, of course, make the total net cost of printing the JOURNAL for the year greater than in any former year The Editor has been assured by the Treasurer, however, that the funds of the Society will probably be adequate to meet this increased cost

Further increases of revenue from membership dues and subscriptions in future years seem to be probable Also it seems probable that additional net income from advertising may be available This would almost certainly be true if additional time of an advertising manager could be secured At least this possibility should be given consideration if a deficiency of funds for printing the JOURNAL should become imminent At present however, the existing arrangements seem to be meeting the situation fairly successfully

In closing the Editor wishes to express to the officers and members of the Society his sincere thanks for the efforts which they have individually made to contribute to the success of the JOURNAL during another year —R W THATCHER, *Editor*

P E Brown Treasurer gave his annual report which was referred to the Auditing Committee

REPORT OF THE TREASURER

I beg to submit herewith the report of the Treasurer for the year November 1, 1925 to November 1 1926

Balance last report, general fund		$1,968 46
Balance last report Lime Assoc fund		147 20
Total balance last report		$2,115 66

RECEIPTS, 1926

Dues, 1926	$2 920 68	
Dues 1926, new	452 50	
Dues, 1925	44 70	
Dues 1927	485 50	
Subscriptions, 1926	857 25	
Subscriptions, 1926 new	207 00	
Subscriptions 1925	75 00	
Subscriptions, 1927	9 00	
Advertising income	1,014 33	
Reprints sold	638 20	
Journals sold	378 41	
Total receipts	$7,082 57	$7,082 57
Total income, 1926		$9,198 23

DISBURSEMENTS, 1926

Printing the JOURNAL—reprints, etc. (13 issues Oct. 1925–Oct. 1926 incl.)	$6,460.33	
Salary Business Mgr. and Asst. Editor	499.92	
Printing (diplomas, programs (2 meetings) stationery, enclosures, statements, postals, certificates, etc.)	201.37	
Postage (Sec'y, Editor, and Bus. Mgr.)	143.10	
Freight, drayage, express and telegrams	27.58	
Refunds on dues, checks returned, etc	39.14	
Miscellaneous items (supplies, bond, expenses of annual meeting, etc.)	264.06	
Total disbursements	$7,635.50	$7,635.50
Balance on hand		$1,562.73
Balance, Lime Assoc. Fund	$ 147.20	
Balance, general fund	1,415.53	
Total balance on hand	$1,562.73	
Total income		$9,198.23
Total disbursements		$7,635.50
Balance		$1,562.73

Respectfully submitted,
P. E. BROWN, *Treasurer.*

The report of the Secretary was read by P. E. Brown and was accepted.

REPORT OF THE SECRETARY

I beg to submit herewith the annual report of the Secretary for the year 1925 to 1926.

Membership.—The membership changes during the year are shown in the following figures:

Membership last report			646
Increase			
New members	103		
Reinstatements	22		
Total increase	125	125	
Decrease			
Resignations	11		
Deaths	1		
Dropped	59		
Total decrease	71	71	
Net increase		54	54
Present membership, 1926			700

The increase in membership, as shown by these figures is certainly quite encouraging Apparently the missionary work among the "heathen" is continuing to bear fruit and more and more are "forsaking their evil ways" and "coming into the fold " There were not quite so many new members secured as was the case last year but there was a smaller loss because of non-payment of dues, so that the total gain for the year is only slightly smaller than that recorded last year

Representatives of the Society at the various colleges and universities were appointed again this year and it is largely due to their efforts that we have secured so many new members The Society should officially thank these men for their efforts to increase our membership It may be of interest to note that 24 of our new members are in foreign countries

After several notices were sent out urging payment of dues, all but 59 "came across with the mazuma apparently getting tired of our dunning letters and of these 59 nineteen were later reclaimed from "outer darkness " It is an encouraging sign that our members are staying by us better than in the past

The membership by states and countries is as follows

UNITED STATES

Alabama	9	Maine	2	Oklahoma	11
Arizona	5	Maryland	14	Oregon	7
Arkansas	4	Massachusetts	6	Pennsylvania	11
California	20	Michigan	15	Rhode Island	2
Colorado	7	Minnesota	17	South Carolina	6
Connecticut	12	Mississippi	3	South Dakota	7
Delaware	2	Missouri	17	Tennessee	6
Dist of Col	52	Montana	13	Texas	26
Florida	10	Nebraska	16	Utah	8
Georgia	15	Nevada	1	Vermont	2
Idaho	5	New Hampshire	2	Virginia	13
Illinois	35	New Jersey	7	Washington	8
Indiana	15	New Mexico	5	West Virginia	9
Iowa	31	New York	36	Wisconsin	22
Kansas	28	North Carolina	4	Wyoming	5
Kentucky	7	North Dakota	13		
Louisiana	6	Ohio	30		
		Total			607

FOREIGN

Alaska	2	Egypt	3	Jugoslavia	1
Africa	6	England	3	Mesopotamia	1
Argentina	2	France	1	New Zealand	1
Australia	2	Germany	4	Peru	2
Brazil	2	Haiti	2	Phil Islands	3
Brit W Indies	2	Hawaii	8	Poland	1
Bulgaria	1	Honduras	1	Russia	2
Canada	23	Hungary	1	Spain	1
China	1	India	2	Sweden	2
Cuba	1	Italy	1	Turkey	2
Denmark	1	Japan	8		
		Total			93
		Total			607
		Total membership			700

Listing the members according to the years in which they came into the Society, the membership is divided as follows:

1908 (Charter)	38	1914	15	1921	45
1908	10	1915	31	1922	44
1909	5	1916	55	1923	32
1910	16	1917	27	1924	46
1911	23	1918	18	1925	109
1912	18	1919	15	1926	102
1913	21	1920	29	1927	1
Total					700

It is of interest to note that 38 of the charter members of the Society are still on our rolls. Note also that we kept 109 of the new members taken in in 1925, an unusual record.

We keep our membership records alphabetically on cards and since 1921 on a loose leaf ledger, by states and by years of election as noted above, so there are four ways to check. If we had three wishes we would wish first that all members would stay in the Society, second that they would pay their dues promptly and third that they would not change their addresses so often. But we might as well wish for anything and so we warn you we shall continue to strive to keep all the members, to collect the dues and to keep your addresses straight no matter how many times you move in a year (you know some people take the JOURNAL with them on vacations—evidently wishing light (?) reading).

Subscriptions.—Our subscription list has increased from 229 to 260 during the year. Fifty-four new subscriptions have been added and 23 were dropped. One of the new subscriptions is for *Biological Abstracts* and is of course being supplied without charge. The subscriptions are being paid for much more promptly than in past years. Evidently our course of education of some of the libraries has had some effect and then too, the demand for the JOURNAL is increasing and libraries find they must keep it.

Journals sold.—There is a constant call for back issues of the JOURNAL and the time is not far distant when the first eight volumes will be out of print. Already Volumes 3 and 4 are out and parts of 5 and 8. One subscriber wrote for a full set and we replied that we could supply all but these volumes which were not available and he advised us that the JOURNAL advertised them for sale. We had neglected to advise Dr. Thatcher of the needed change in advertising but did so at once. Thus do our "sins of omission" find us out. If anyone has tried sending packages to foreign countries and especially to the Union of Socialist Soviet Republics commonly known as Russia, you know of the red tape involved. It is quite an interesting proposition. Your life history has to be on the package, together with an address containing all the X's and Z's you can imagine, sealed with wax and stamped with a special seal on the wax, tagged and so on. We finally have learned the combination but it takes our personal dray to get the packages started right.

Treasurer's bond.—The Treasurer's bond has been renewed so the Society is protected to the extent of $2,500 from theft, fraud, chicanery, or flight of the Treasurer with the vast horde of the Society's wealth. Perhaps it might be well to have a depository bond also. We shall look into the cost of one.

Finances.—Our finances are in good condition as appears from the Treasurer's report, and we may say that as Secretary we keep an eye or two on the Treasurer. Dr. Thatcher wrote a short time ago to learn of our condition as he wanted to spend the money. We told him to go to it for the JOURNAL as it is now appearing is being generally commended and we want to keep our finances in such shape that we can keep the JOURNAL in good shape so that our finances shall be in good shape and so on *ad libitum*.

Fellowship nominations.—The ballots for Fellows were sent from our office to the Executive Committee and it was a matter of great relief and pleasure to us to have the committee quickly agree on the five men who are to be honored this year with election to Fellowship. Their diplomas have been prepared and will be presented.

Affiliation of societies.—On March 2, I received word from Prof. R. P. Bledsoe of Georgia advising me that the Agronomy Section of the Southern Agricultural Workers· Association had unanimously voted to affiliate with the American Society of Agronomy. Someone should do some missionary work with that Western Plant Nutrition Society and get them to affiliate with us.

Appointments.—The regular standing committees of the Society were appointed by President Williams and in addition he continued the three special committees, one to arrange for the International Soil Congress, one on Corn Investigations, and one on the Study of Fertilizer Distributing Machinery. The personnel of these three committees remained unchanged.

Dr. C. H. Myers being called out of the country before the meeting of the International Plant Congress, Dr. R. G. Wiggans was appointed to complete the arrangements for the Agronomy program. This was done and a very successful meeting is reported.

A special committee was appointed to cooperate with a similar committee from the Economic Entomologists in the study of methods to prevent the spread of the corn borer. This committee consists of L. E. Call, Kansas, Chairman; W. L. Burlison, Illinois; J. F. Cox, Michigan; R. M. Salter, Ohio; and F. D. Richey, U. S. Department of Agriculture.

Dr. R. A. Oakley was appointed in place of Dr. Piper as our representative tc the Institute for Research in Tropical America.

Invitations were received to send representatives to the Pan Pacific Congress in Tokio and to the Congress of the French Society of Industrial Chemistry in Brussels, but no one being available, no delegates were named.

In connection with the work of the sub-committees on Registration of Varieties of grains it might be mentioned that the printing of a registration certificate was handled by our office.

Meetings.—The Summer Meeting of the Corn Belt Section of the Society was held at Minnesota. The programs were printed and sent out from our office. A most successful meeting was held.

The Western Agronomists report a very interesting meeting. The New England section held a fine meeting on December 4 and 5, 1925. Reports of these meetings were given in the JOURNAL.

Programs for the Annual Meeting were distributed to all the membership of the Society. President Williams and the symposia leaders had their material in promptly and so the programs went out by the middle of October.

No separate program was given last year at the American Association meeting, but we met with Section O and the Phytopathologists. This year Dr. Kiesselbach is arranging a symposium on "Small Grain Breeding" for the Philadelphia meeting.

Correspondence.—The usual extensive correspondence has occupied much time during the year. There are many letters going out from our office practically daily pertaining to the dues, sale of Journals, subscriptions, meetings, etc. In addition there is a vast mass of correspondence with cities, convention bureaus, hotels, printing companies, reporters, bus companies, entertainment providers, photographers, badge companies, and so on.

Twenty cities have invited us to hold our next meeting within their "wonderful, inspiring, beautiful, delightful, picturesque" etc. domains. California can't lay claim to all the hot air advertising. Other cities have told as many big stories as Los Angeles. In fact we have considered moving our office to some one of these towns, the attractions are so well advertised. If we had to choose our next meeting place would it be Niagara Falls, San Francisco, Memphis, Charleston, Los Angeles, Denver, Atlantic City, Philadelphia, Chicago, Pittsburg, Norfolk, Toronto, Springfield (Mass.), Minneapolis, Asbury Park, Madison, Cleveland, New York, Briar Cliff Lodge, or some other place? Hotels by the dozen have written us. We could have a choice of a dozen reporters for our meetings. We could have our pictures taken several times, with the Washington Monument (or what have you) as a background. In fact we may have a photographer yet to judge from our last letter from one firm. Bus companies will haul you anywhere you wish to go. Printers besiege us. Entertainment of various kinds could be provided, speakers, dramatic sopranos, music, etc. All the wonderful chances we have to turn down because our banquet features a business session and an address by our President. We have received special membership and special privilege cards for many places—roof gardens, etc.—one we have with us—to the Spanish Village—our title is "Guest Memba"—we are cordially urged to visit Washington's most exclusive night club. Probably we shall go yet tonight. We have communications from the "All America Standards Council" urging the adoption of the metric system, from the Citizens Committee of One Thousand urging that we will give place on our program to the important question of law observance and enforcement. We urge you all to observe the law while in Washington for strangers in the city are dealt with severely while we understand the residents do as they please.

In closing we wish to express our appreciation of the aid, courtesy and suggestive help given by President Williams and Editor Thatcher in the various matters engaging the attention of our office during the year.

Respectfully submitted,
P. E. Brown, *Secretary.*

COMMITTEE REPORTS

TERMINOLOGY

C. R. Ball reported for the Committee on Terminology telling of the progress which has been made by that Committee. The work on definition of terms has been halted by the death of Dr. C. V. Piper, for years Chairman of the Committee, but much material has been accumulated and we may look for definite recommendations from this committee in the near future.

STANDARDIZATION OF FIELD EXPERIMENTS

S. C. Salmon reported for the Committee on Standardization of Field Experiments as follows:

The committee feels that care in obtaining comparable experimental results with forage crops may well be stressed. The Society has already made certain recommendations in this regard, but it seems desirable to make these somewhat more specific. Hence, it is suggested that the following be made a part of the standards previously adopted by the Society and published in the JOURNAL (13:368. 1921), with minor changes as published in a later number of the JOURNAL (14:359. 1922).

1. Yields of forage crops should be reduced systematically to a comparable moisture basis—either moisture free, thoroughly air dry, or with yields calculated from a moisture-free basis to a definite uniform moisture content.

2. In the case of some forage tests, such as planting rates or tests with varieties some of which are subject to severe winterkilling, the crops harvested from various plats may differ decidedly in weed content. In such cases the percentage of weeds in the crop should be indicated by weight.

3. Harvesting forage crop varieties in comparative test plats should be done as far as possible at comparable stages of maturity or at least at stages consistent with good farm practice for the particular crop. In all cases where early and late varieties are being compared the harvesting should be done so that the optimum yield for every variety may be obtained. This will often mean that different varieties are harvested at different dates. Orange sorgo should, for example, be harvested at a later date than Black Amber in order to obtain a correct expression of varietal difference, but if the Black Amber represents as late maturity as the particular territory will permit, then the two should be harvested together.

S. C. SALMON, *Chairman.*
H. H. LOVE
C. A. MOOERS
L. J. STADLER
T. A. KIESSELBACH

VARIETAL STANDARDIZATION

H. K. Hayes presented the report of the Committee on Varietal Standardization as follows:

The first published report of registered varieties of wheat, oats, and barley appeared in a recent number of our JOURNAL. It is evident that as time goes on registration will help materially in a standardization of crop varieties. The published reports, likewise, should be of much historical interest.

The cooperative program under the Purnell Fund for the improvement of corn by the method of selection in self-fertilized lines and their recombination leads to the belief that in the very near future a system of registration of selfed lines of corn which are used in hybrid combinations and of the hybrid combinations themselves will be desirable. It is proposed, therefore, that (1) the American Society of Agronomy authorize the registration of F_1 hybrid combinations, i. e., single or double crosses, and of selfed lines of corn; (2) that the method of determination of the value of hybrid combinations be similar to that adopted for the small grains, with the reservation that such hybrid combinations must be produced from selfed strains which are practically homozygous and which have been selfed for at least five generations; and (3) that the selfed strains used in these hybrid combinations be registered at the same time.

It is hoped that in the next few years plans may be completed for each of our important farm crops for the registration of varieties of demonstrated merit. It is the feeling of the committee, based on experience in registering varieties, that the subcommittees in the future shall register on merit alone, and this merit shall be established by yield and other data required; and that the approval of this report shall empower the general committee to appoint subcommittees on various crops in the future as occasion arises.

It is evident that there is much variation in the terminology now used by the various state crop improvement organizations. In one state, the term "registered" is used for the same sort of seed which in another state is referred to under some other terminology. We suggest that the term "registered" be used only for the seed of those varieties that have been registered by the American Society of Agronomy and that standard terminology be developed for the approved seed of other varieties. The International Crop Improvement Association and the Seed Marketing Conference is at present studying these questions. It is suggested that a committee of three of the American Society of Agronomy be appointed to cooperate with a similar committee from the International Crop Improvement Association in an effort to develop standard terminology for seed of improved varieties.

Those members of the Committee present:

H. K. HAYES, *Chairman.*
H. V. HARLAN
H. H. LOVE
J. ALLEN CLARK
T. R. STANTON

BARLEY REGISTRATION

H. V. Harlan reported for the subcommittee on barley registration, noting that four varieties had been submitted for registration, three being accepted and published in the JOURNAL.

OATS REGISTRATION

T. R. Stanton reported for the subcommittee on oats registration as follows:

The subcommittee is pleased to report that during the year material progress has been made in the registration of oat varieties. The first registration list, including 42 standard and 22 improved varieties, has been published (Jour. Amer. Soc. Agron., 18: 935-937, 1926) by the Society. Certificates of registration also have been presented by the Society to the institutions and officials submitting the improved sorts for registration. The subcommittee desires to take this opportunity to urge that the registration of varieties be continued, and that experiment station officials and others interested in the improvement of oats submit to the chairman of the subcommittee applications for registration of promising new varieties which they believe eligible for Registration. Registration blanks will be furnished on application to the chairman of sub-committee.

T. R. STANTON, *Chairman.*
FRED GRIFFEE

WHEAT REGISTRATION

J. A. Clark reported for the subcomittee on wheat registration as follows:

The first official registration of wheat varieties under the cooperative plan of the American Society of Agronomy and the Bureau of Plant Industry, U. S.

Department of Agriculture, has been reported in the October, 1926, issue of the JOURNAL Two hundred and twenty-nine standard varieties were registered, which included all of the varieties keyed and described as distinct varieties in the Classification of American Wheat Varieties, U S D A Bull 1074 There also were 23 improved varieties registered on the basis of merit Certificates of registration were issued for these There are 10 or 12 additional varieties which are commercially grown and probably eligible for registration in the United States and Canada The committee urges the cooperation of all agronomists, and it is hoped that during the coming year applications for the improved varieties of wheat which have not yet been registered may be received by the committee

J ALLEN CLARK, *Chairman*
H H LOVE
J H PARKER

CROPS TEACHING METHODS

No report was given by this committee

SOILS TEACHING METHODS

F E Bear presented a statement from the chairman of the committee, H O Buckman, and suggested that the statement be considered a report of progress and the committee be continued, to consist of only three members H L Walster read a letter sent to the chairman of the committee and discussed some phases of soils teaching work He moved that a special committee of three be appointed to attend and represent the Society at the Sessions of the Society for the Promotion of Agricultural Teaching and the joint session with the Association of Land Grant Colleges in the Section on Resident Teaching Motion carried

CORN PROJECTS

F D Richey, Secretary, reported for the special committee on corn project, that its recommendations had been published in the JOURNAL (18 306–363, 823–829, 1926), that a conference of corn workers from the states involved had met in accordance with the committee's recommendation, and that the committee had therefore fulfilled the function for which it was created He moved the adoption of the report and the discharge of the committee Motion carried

INTERNATIONAL CONGRESS OF SOIL SCIENCE

A G McCall presented the following report of J G Lipman, Chairman of the special committee in charge of arrangements for the International Congress of Soil Science

AMERICAN ORGANIZING COMMITTEE

At the November, 1925, meeting of the American Society of Agronomy, the Executive Committee was authorized to appoint a subcommittee on the International Congress of Soil Science Accordingly, Messrs Marbut, McCall, and Lipman were designated to serve on that committee. They were given authority to add to the committee's membership Hence, in attempting to organize a widely representative group, the original members of the committee obtained the cooperation of the individuals whose names are herewith given.

M. S. Funchess, Ala.
P. S. Burgess, Ariz.
Martin Nelson, Ark.
D. R. Hoagland, Calif.
W. P. Headden, Col.
M. S. Morgan, Conn.
T. F. Manns, Del.
R. W. Ruprecht, Fla.
J. R. Fain, Ga.
G. R. McDole, Idaho
W. L. Burlison, Ill.
S. D. Conner, Ind.
P. E. Brown, Iowa
R. I. Throckmorton, Kan.
J. S. McHargue, Ky.
C. W. Edgerton, La.
G. E. Simmons, Me.
A. G. McCall, Md.
S. B. Haskell, Mass.
M. M. McCool, Mich.
F. J. Alway, Min.
J. R. Ricks, Miss.
M. F. Miller, Mo.
L. F. Gieseker, Mont.
W. W. Burr, Neb.
Robert Stewart, Nev.
F. W. Taylor, N. H:
J. G. Lipman, N. J.
H. V. Jordan, N. Mex.
T. L. Lyon, N. Y.
W. B. Cobb, N. C.
H. L. Walster, N. D.
F. E. Bear, Ohio
W. L. Powers, Oreg.
J. W. White, Penn.
H. C. Henricksen, P.R.
B. L. Hartwell, R. I.
H. W. Barre, S. Car.
A. N. Hume, S. Dak.
W. H. McIntire, Tenn.
G. S. Fraps, Texas
J. E. Greaves, Utah
E. Van Alstine, Vt.
W. B. Ellett, Va.
F. J. Sievers, Wash.
E. P. Deatrick, W. Va.
E. Truog, Wisconsin
A. F. Vass, Wyoming
B. E. Livingston, U.S.D.A.
C. F. Marbut, U.S.D.A.
Oswald Schreiner, U.S.D.A.
K. F. Kellerman, U.S.D.A.
F. T. Shutt, Canada
F. A. Wyatt, Canada
R. Harcourt, Canada

It will be noted that, aside from representatives from the several states, there are serving on the committee representatives of the Federal Department of Agriculture as well as of the Canadian provinces.

CONGRESSIONAL AUTHORITY

Joint Resolution No. 10 was signed by President Coolidge. This reads as follows:

"Joint Resolution Authorizing and requesting the President to extend invitations to foreign governments to be represented by delegates at the International Congress of Soil Science to be held in the United States in 1927.

"Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the President be, and he is hereby, authorized and requested to extend invitations to foreign governments to be represented by delegates at the International Congress of Soil Science to be held in the United States in 1927.

Approved, April 3, 1926."

In keeping with the provisions of this resolution, our Department of State is to instruct the American Consul representatives abroad to invite foreign governments to send official delegates to the Congress.

PROGRAM

The program of the Soil Science Congress is to be organized under six sections or, as they are better known to our European colleagues, commissions. These are:

I. Commission on Soil Physics.
II. Commission on Soil Chemistry.
III. Commission on Soil Bacteriology.
IV. Commission on Soil Fertility.

V. Commission on Nomenclature, Classification and Cartography.

VI. Commission on the Application of Soil Science to Land Utilization.

The officers of these sections are:

I. President: Prof. Dr. V. Novak, Brno, Czechoslovakia.

Vice-President: Dr. B. A. Keen, Rothamsted, England.

Secretary: Dr. L. Smolik, Brno, Czechoslovakia.

Preliminary meeting held October 15, 1926, at the Rothamsted Experimental Station, England.

II. President: Prof. Dr. A. deSigmond, Budapest, Hungary.

Vice-Presidents: Dr. B. Aarnio, Helsinki; Prof. Dr. M. M. McCool, East Lansing, Michigan; Prof. Dr. K. A. Vesterberg, Stockholm; Prof. Dr. Georg Wiegner, Zurich.

Secretaries: Prof. Dr. Robert Ballenegger, Budapest; Prof. Dr. Norman M. Comber, Leeds; Prof. Dr. Th. Saidel, Bucuresti; Dr. E. Scherf, Budapest; Dr. E. Truog, Madison, Wisconsin.

Preliminary meeting held April, 1926, in Groningen, Holland.

III. President: Prof. Dr. J. Stoklasa, Prague, Czechoslovakia.

Vice-Presidents: Dr. S. A. Waksman, New Brunswick, N. J.; Dr. H. R. Christensen, Copenhagen; Dr. Niklas, Weihenstephen, Germany; Dr. G. Rossi, Portici, Italy.

Secretaries: Dr. D. W. Cutler, Harpenden, England; Dr. A. Nemec, Prague, Czechoslovakia; Dr. H. J. Conn, Geneva, New York; Dr. E. B. Fred, Madison, Wisconsin; Dr. Doerell, Prague, Czechoslovakia.

Preliminary meeting held November, 1926, in Berlin.

IV. President: Prof. Dr. E. A. Mitscherlich, Konigsberg i, Pr.

Vice-Presidents: Dr. Harald R. Christensen, Kopenhagen; Dr. K. Zijlstra, Groningen.

Secretary: Dr Olof Arrhenius, Stockholm.

Preliminary meeting held September 21, 1926, at Dusseldorf, Germany.

V. President: Prof. C. F. Marbut, Washington, D. C.

VI. President: Dr. J. Girsberger, Zurich, Switzerland.

Vice-President: Dr. S. H. McCrory, Washington, D. C.

MEETINGS OF THE SOIL SCIENCE CONGRESS

Arrangements have been made by the Washington group of the Organizing Committee for space in the National Museum and at George Washington University. The section and joint meetings are to be held during the period June 13 to 22, 1927. It is proposed that abstracts of all of the papers be printed in three languages and that insofar as possible the complete papers be also printed prior to the assembling of the Congress. This would obviate the need of reading the papers themselves but would allow ample time for their discussion.

EXHIBITS

Extensive exhibits of soil columns from North and South America, Europe, and Asia are to be installed. An effort will be made also to organize creditable exhibits of fertilizer raw materials, fertilizers, apparatus, cultures of microorganisms, soil maps and of other exhibits of more or less direct interest to students of soils.

FIELD EXCURSION

Immediately after the adjournment of the Congress, a field excursion will be undertaken by delegates and members. This field excursion will follow a carefully outlined itinerary. An opportunity will be given to the members of the party to become acquainted with the important soil provinces of the United States, crop zones and industries directly or indirectly concerned with agriculture. A number of the leading agricultural colleges and experiment stations will also be visited. The field excursion will occupy a period of about one month and will permit the party to go to the Pacific Coast by a southern route and return east by a more northern route. Chambers of Commerce, state colleges and universities and other organizations as well as individuals will participate in organizing a satisfactory field excursion.

HOUSING, ENTERTAINMENT, ETC.

Provision will be made for suitable housing of the members of the Congress at Washington as well as for semi-official and non-official entertainment. Special committees will be organized to look after the comforts of the ladies accompanying the members of the Congress.

FINANCES

It is estimated by the American Organizing Committee that the sum of about $60,000 will be needed for meeting the expenses of the Congress. The largest item in the budget is that of entertaining the official delegates from other countries who will participate in the field excursion as guests of the American Organizing Committee and of the societies sponsoring the activities of the Organizing Committee. The translating and printing of the abstracts and papers, the installing of exhibits and the services of the Executive Secretary and of his assistants will represent the other important items in the budget. It is expected that the entire amount that may be needed will be in the hands of the Treasurer of the Congress some time prior to the beginning of the meetings. More than two-thirds of the funds needed are already in sight.

The members of the Organizing Committee would express their keen appreciation of the interest and support which has been given them by the American Society of Agronomy and its officers.

J. G. LIPMAN, *Chairman.*
A. G. MCCALL
C. F. MARBUT

COOPERATION WITH NATIONAL RESEARCH COUNCIL

No report was given by the committee. C. W. Warburton reported that R. A. Oakley, Chairman of the Committee, is in California, recuperating from illness.

STUDY OF FERTILIZER DISTRIBUTING MACHINERY

S. B. Haskell reported progress in the work of this special committee.

CORN BORER INVESTIGATIONS

L. E. Call, Chairman, presented and read the following report of the special committee on corn borer studies:

The European corn borer, which was first discovered in the western infestation area of the United States in the summer of 1920, has made a natural spread until at the present time (September, 1926) the insect occurs throughout a strip of territory varying from 75 to 150 miles wide in the Lake Erie districts of New York, Pennsylvania, Ohio, Michigan, Indiana, and Ontario. Although drastic measures are being taken to place in operation every known agency to prevent the spread and to reduce the intensity of infestation, the insect is spreading in all directions at a rate of from 20 to 30 miles per year, and the infestation is increasing in intensity.

Those familiar with the habits of the corn borer and those who have observed crop losses in the principal dent corn growing districts of Ontario, are convinced that the insect is of tremendous potentiality and ranks as one of the most alarming crop pests that has ever become established in America. Threatening as it does the corn crop of this country, upon which the great livestock industry depends for roughage and grain, the situation presents the possibility of a national calamity which calls for the keenest knowledge of the scientist, and wisest judgment of the state and government officials, and the closest cooperation of the growers.

The committee, appointed to inves igate the possibility of closer cooperation between entomologists and agronomists in combating the European corn borer, wishes to endorse and give its hearty approval to the efforts that have been made to prevent the spread of the corn borer and to commend those engaged in directing the research in this field for the extensive coorperative experiments now under way to develop effective means for the control of the insect. It would seem that little has been omitted in planning and conducting both the quarantine and research work. It is the purpose and wish of this committee to assist in every possible way to marshall all forces in an effort to give every possible support and encouragement to the extensive research now under way. With this purpose in mind, the committee suggests and recommends:

1. That the state agricultural experiment stations, the state departments of agriculture, and all other agencies interested in the welfare of agriculture give their support and encouragement to the federal government toward a continuation of present policies in respect to quarantines and quarantine enforcement. Realizing, however, that with the continued spread of the borer, it may be necessary to modify the quarantine and scouting programs within the next few years, that scouting work in the area not known to be infested by the European corn borer, but apparently subject to infestations, be continued, and that the scouting work be extended further to uninfested areas in the large corn-producing states where such areas seem particularly exposed to infestations.

2. That the cooperative projects in the infested areas now underway between agronomists and entomologists of the state and federal governments to determine the best types, varieties, and strains of corn to use under corn borer conditions be continued. Studies to determine the best time to plant different sorts to escape commercial damage also should be continued. Agronomists and plant breeders should endeavor to find strains of corn which may have some natural resistance. Efforts also should be made to determine the possibility of developing strains which may be planted at the optimum time to escape severe infestation and yet yield profitable returns. These projects should be continued for a sufficient time to be reliable and to be conducted under different climatic conditions.

3. That similar projects with respect to types, time of maturing, yields, etc., be started in the corn states not yet infested with the European corn borer.

4. The continuation of the projects now under way to introduce all effective parasites of the corn borer from Europe and Asia. The enlargement of these projects to include an intensive survey of the parasite possibilities throughout the known world distribution areas of the corn borer. These investigations should include a comprehensive study of the biology, host relationships, etc., of the introduced species after they become adapted to North American conditions.

5. The continuation of the studies relating to the biology and ecology of the corn borer under North American conditions with special emphasis upon the facts needed for the effective control of the species.

6. The continuation of biological investigations in the presumed native home of the insect (Europe) with especial emphasis upon the determination of ecological influences responsible for the development of areas of chronically severe, or chronically light infestation, or variable infestation as the case might be, together with the application of these findings to North American areas with the same or similar ecological environment. This involves a study of the influences responsible for one-generation or two-generation development, the status of parasites, variety of crops, damage, seasonal history, cultural methods, control methods, distribution and meteorological data, etc.

7. That we express our appreciation for the excellent progress that has been made in the development of machinery for cutting corn close to the ground, for ensilage cutting, and for shredding or otherwise handling corn in the field so as to destroy all the corn borers in the stalks and stubble after the corn is gathered. These investigations, together with the studies of attachments to plows that will facilitate the turning under of high stubble or standing corn stalks should be continued.

8. That the experiments to determine the value of plowing under corn debris as a means of destroying the corn borer larvae be continued. Such studies should include a determination of the comparative value of fall and spring plowing, of different dates and depths of plowing.

9. The continuation of the field surveys to determine the annual increase in dispersion and intensification of infestation.

10. Since the burning of the crop residues is an effective means of assisting in the control of the European corn borer, we recommend that further studies be carried on to determine the effect of the burning of corn residues on soil productivity.

11. That work upon insecticides and chemotaxis be resumed in the hope of finding methods by the use of which the individual grower can protect his crops.

12. That we recommend to those engaged in research along agronomic and animal nutrition lines that they study rotations with special reference to determining the degree to which it may be possible or desirable to substitute less susceptible crops for corn in those sections where the corn borer promises to become a serious pest.

13. That we suggest a thorough investigation of the possible further commercial utilization of corn residues.

14. That further attention be given in one-generation areas to weeds and other plants than corn to determine what part such plants may play in the future as breeding hosts of the borer, especially in districts where, owing to the severity of the infestation, corn growing may be abandoned temporarily,

15. That we recommend to the extension service of the state and federal governments that they take every opportunity by demonstrations, exhibits and

lectures to acquaint their constituencies with the gravity of the corn borer, the nature of the insect and its work, together with methods of meeting the situation. The need of the cooperation of every grower in the regions adjacent to the infested area as well as those within recognized corn borer territory should be emphasized.

16. That state and government publications be issued to keep the public fully informed regarding the development of the European corn borer situation. Annual mimeographed or printed reports of progress for distribution to interested workers also would be desired.

17. That the committee act as a clearing house in advancing corn borer control measures by obtaining opinions from the entomologists and agronomists as to the lines of research and other methods which should be pursued, with special reference to needed investigations not now under way and which may have a practical application to the problem.

18. That the committee may be of service to the Secretary of the United States Department of Agriculture, the Canadian Minister of Agriculture, and other administrative officials, or to legislative bodies who are charged with making the final decisions in matters regarding appropriations and general policies affecting corn borer research and control by keeping them informed of the progress of the work and of field conditions, and by furnishing needed information relating to results of experiments and the requirements for continued work.

19. That we recommend that all states where European corn borer occurs pass legislation at the next session of the legislature authorizing the state department in charge of operating quarantines to stop and search vehicles and other carriers to ascertain if they are carrying corn or other produce that might be infested with the corn borer, and if contraband, to seize or prevent it from leaving the quarantined area. Also, that the states promulgate compulsory clean-up regulations that are adapted to their respective conditions in order to give greater assurance of the destruction of the corn borer.

20. It is recommended that copies of all written reports or recommendations of the committee be made available to the Secretary of the United States Department of Agriculture and the Canadian Minister of Agriculture.

Respectfully submitted by the joint committee of entomologists and agronomists,

Committee of the American Association of Economic Entomologists:

GEORGE A. DEAN, *Chairman*
LAWSON CAESAR
J. J. DAVIS
C. J. DRAKE
D. J. CAFFREY

Committee of the American Society of Agronomy:

L. E. CALL, *Chairman*
W. L. BURLISON
J. F. COX
R. M. SALTER
F. D. RICHEY

SPECIAL COMMITTEE

T. L. Lyon, Chairman of the special committee to consult with a committee from the Soil Survey Association regarding the dividing of the members of the Agronomy Society into two groups—Soils and Crops—reported that it seemed desirable that the American Society of Agronomy sponsor the International Congress of Soil Sciences, and hence it seemed that the membership of the Society should be grouped so that the soils specialists would be in a separate group and this group be the sponsor of the Congress. He moved that the Society membership be divided as suggested into a Soils group and a Crops group, the grouping to be arranged by the Executive Committee and that the Soil Congress be held under the auspices of the Soils Section of the American Society of Agronomy with the affiliated American Soil Survey Association. Motion carried.

AUDITING

W. W. Burr presented the report of the Auditing Committee, stating that the books and vouchers for the Treasurer had been examined and found correct.

RESOLUTIONS

R. W. Thatcher presented the report of the Committee on Resolutions as follows:

1. The Committee recommends that the Society adopt the following resolution, which has been previously adopted by the Western Section and by it transmitted to the Society for action:

"WHEREAS, definite information is urgently needed upon the adaptability of domestic forage crop seeds;

"AND WHEREAS most of the State Experimental Stations are not financially able to carry on such investigations, most of which are of inter-state interest;

"*Be It Resolved*, That we urge that every effort be made to increase the appropriation of the Office of Forage Crops Investigations of the United States Department of Agriculture sufficiently to carry on these investigations in cooperation with the State Experimental Stations."

2. The Committee recommends further the adoption of the following resolutions of appreciation of services rendered:

The thanks of the American Society are due and are hereby expressed to the management and employees of the New Willard Hotel and the Hamilton Hotel for their courtesy and hospitality during the present meetings.

The Society hereby expresses its thanks to the Soil Improvement Committee of the National Fertilizer Association and to Professor A. G. McCall for the use of the lanterns at the sessions of today and tomorrow.

To those who have arranged the symposium programs for this meeting, the thanks of the Society are due and are hereby most heartily voted.

The record of the years work which has been presented tonight is ample evidence of the untiring and devoted efforts of the retiring officers of the Society. To them the hearty appreciation and sincere thanks of the Society are hereby tendered.

3. The Society records with the deepest regret the death of C. V. Piper, which occurred on February 11, 1926. A faint measure of the indebtedness of the Society to Dr. Piper as a member and officer and of science in general to his tremendous energy and efforts during a life-time of unselfish service, has been reflected in the remarks made tonight by his co-workers and in the articles which have appeared in the JOURNAL.

R. W. THATCHER, *Chairman.*
ANDREW BOSS
B. L. HARTWELL

NOMINATING

C. R. Ball gave the report for the Nominating Committee as follows: ***Representative on Committee on Cooperation with National Research Council,*** J. G. Lipman (5 years). ***Representative on the Union of Biological Societies,*** R. W. Thatcher (2 years). ***Representatives to the American Association for the Advancement of Science,*** R. J. Garber and H. H. Love. ***Fourth Vice-President,*** W. W. Burr. ***President,*** W. L. Burlison. The report was adopted and the nominees named declared elected to the various offices.

W. L. Burlison, President-elect, was called on and responded with a few words of appreciation of the honor conferred upon him.

COUNTY AGENTS

O. S. Fisher presented the county agents in attendance at the meeting who had won the contest sponsored by the Soil Improvement Committee of the National Fertilizer Association for the best county soil fertility program.

FELLOWS

W. L. Burlison called upon those who were elected Fellows last year to stand. Those present were, L. E. Call, R. W. Thatcher, C. R. Ball, S. B. Haskell, M. F. Miller, T. L. Lyon, C. W. Warburton, and P. E. Brown. Letters from C. E. Thorne and C. A. Zavitz stated their regret that they could not be at the meeting. J. G. Lipman was also unable to be present.

C. W. Warburton spoke of the death of C. V. Piper, who was elected a Fellow last year, and read a tribute to Dr. Piper and his work which had been written by R. A. Oakley.

It was moved and carried that the Secretary send letters of greeting to Professors Thorne and Zavitz.

The Fellows elected this year were then presented to the Society, a brief statement of the record and accomplishments of each being given. Diplomas were then presented. The men elected to Fellowship were: B. L. Hartwell, C. G. Williams, H. H. Love, Emil Truog, and C. A. Mooers.

MORNING SESSION, FRIDAY, NOVEMBER 19

SOILS SECTIONAL PROGRAM

SYMPOSIUM—"POTASH"

Leader: C. A. Mooers, Director, Tennessee Agricultural Experiment Station

1. "The Geography of Potash Needs of the Soil Provinces"
   J. N. Harper, Director, Bureau of Agricultural Information, French Potash Society
2. "Relative Crop Response"
   B. L. Hartwell, Director, Rhode Island Agricultural Experiment Station
3. "Potash in Relation to Plant Diseases"
   G. N. Hoffer, Department of Botany, Indiana Agricultural Experiment Station
4. "Influence of Liming on Availability of Soil Potash"
   W. H. MacIntire, Department of Soil Chemistry, Tennessee Agricultural Experiment Station

5. "Potash in Relation to Quality of Crop"
   G. L. Schuster, Department of Agronomy, Delaware Agricultural Experiment Station

FARM CROPS SECTIONAL PROGRAM

SYMPOSIUM—"CROP ROTATION"

Leader: W. W. Weir, Bureau of Soils, U. S. Dept. of Agriculture

1. "Crop Rotation in Relation to Soil Productivity"
   T. C. Johnson, Director, Virginia Truck Experiment Station
2. "Crop Sequence, a Principle of Rotation"
   Firman E. Bear, Department of Soils, Ohio State University
3. "Legumes and Grasses in Crop Rotation"
   T. L. Lyon, Department of Agronomy, Cornell University
4. "Rotation in Relation to the Agriculture in the Corn Belt"
   A. T. Wiancko, Department of Soils and Crops, Purdue University
5. "Crop Rotation in the Great Plains Area"
   H. L. Walster, Department of Agronomy, North Dakota Agricultural College
6. "Crop Rotation in Relation to Southern Agriculture"
   M. J. Funchess, Dean and Director, Alabama Polytechnic Institute

AFTERNOON SESSION, FRIDAY NOVEMBER 19

SOILS SECTIONAL PROGRAM

SYMPOSIUM—"SOIL ORGANIC MATTER"

Leader: Firman E. Bear, Department of Soils, Ohio State University

1. "Some Physical and Physico-Chemical Properties of Soil Organic Matter"
   B. A. Keen, Soil Physicist, Rothamsted Experiment Station, England
2. "Organic Matter Supplied in Crop Residues"
   E. E. DeTurk, Department of Agronomy, University of Illinois
3. "Organic Matter Requirements of Soil Under Various Climatic Conditions"
   J. C. Russell, Department of Agronomy, University of Nebraska
4. "Soil Organic Matter and Manurial Treatments"
   J. W. White, Department of Agronomy, Pennsylvania State College
5. "The Chemical Composition of Organic Matter as Related to its Effectiveness"
   Fred J. Salter, Department of Soils, Ohio State University

FARM CROPS SECTIONAL PROGRAM

SYMPOSIUM—"PLANT BREEDING"

Leader: H. K. Hayes, Department of Agronomy, University of Minnesota

1. "The Relation of Triploid Factors and Chromosome Groups in Wheat and Oats"
   E. F. Gains, Department of Farm Crops, Washington State College
   Discussion led by L. J. Stadler, University of Missouri

2. "Breeding Wheat for Resistance to Physiologic Forms of Black Stem Rust"
   O. S. Aamodt, Bureau of Plant Industry, U. S. Dept. of Agriculture
   Discussion led by C. E. Leighty, Bureau of Plant Industry, U. S. Dept. of Agriculture
3. "Breeding Improved Varieties of Forage Crops"
   L. E. Kirk, University of Saskatchewan, Canada
   Discussion led by P. C. Mangelsdorf, Connecticut Agricultural Experiment Station
4. "Accurate Determination of Dry Matter in Forage Crops"
   G. P. McRostie, Dominion Department of Agriculture, Canada
   Discussion led by T. A. Kiesselbach, University of Nebraska

Meeting adjourned.

P. E. Brown, *Secretary.*

NEWS ITEMS

Donald D. Hill, after obtaining the degree of Master of Science at the Kansas Agricultural College in June, was appointed Instructor in Agronomy and Assistant in the Department of Farm Crops at the Oregon Agricultural College, to succeed C. C. Ruth. He plans to leave Kansas in February, at the end of the present semester.

Irving J. Jensen, Assistant Professor of Agronomy and Assistant Agronomist in the Montana College of Agriculture and Experiment Station, has accepted the superintendency of the Judith Basin Substation at Moccasin, Montana, in place of Albert Osenberg, transferred.

Oscar R. Mathews, Associate Agronomist at the U. S. Belle Fourche Field Station, Newell, S. Dak., has been made Superintendent of the U. S. Dry-Land Field Station, Ardmore, S. Dak., vice Floyd L. Kelso.

Le Roy Powers, who has been assisting in experiments in irrigated crops at the Huntley Substation, Huntley, Montana, is to be transferred to Bozeman to take the position of Assistant Professor of Agronomy and Assistant Agronomist at the College and Station, in place of I. J. Jensen. Mr. Powers is a graduate of the Montana State College, with graduate training under Dr. E. F. Gaines, of Washington State College.

Howard B. Sprague, formerly Assistant Agronomist in the New Jersey Agricultural Experiment Station, accepted the position of Assistant Instructor and Assistant Agronomist in the Minnesota College of Agriculture and Experiment Station, where he succeeded Dr. H. F. Steinmetz, effective in September.

A. F. Lebedeff, Professor of Agriculture and Director of the Plant Breeding Station at the University of Rostoff, South Russia, with his wife and son, has been visiting American agricultural experiment stations and the Department of Agriculture for several months. Dr. Lebedeff has made contributions on the physiology of bacteria, especially in the field of oxidation and reduction, and has studied carbon assimilation and denitrification by bacteria. He also has contributed in the field of soil physics, having published extensive researches on the rôle of water vapor and the movement of water in the soil. The Russian Geographical Society has awarded him the Semenov-Tjanshansyns medal for his work. Dr. Lebedeff is now collaborating with C. F. Marbut of the U. S. Bureau of Soils, and H. H. McKinney of the Office of Cereal Crops and Diseases, U. S. Bureau of Plant Industry, in the study of the film water in clay soils. He hopes to determine the quantity of film water by means of a high-speed centrifuge. Dr. Lebedeff also plans to attend the International Soils Congress which is to be held in Washington, D. C., in June, 1927.

B. A. Brown, Agronomist of the Storrs Agricultural Experiment Station in Connecticut, is on leave of absence for graduate study at the University of Wisconsin for the first term of the academic year.

J. H. Parker returned to his duties as Professor of Crop Improvement at the Kansas State Agricultural College at Manhattan on October 1, after a year spent in graduate study at Cambridge University in England, under a fellowship of the International Education Board.

W. H Metzger and D. D. Hill have been appointed as research assistants in agronomy at the Kansas State Agricultural College.

T. S. Buie has been appointed Chief of the Agronomy Division at Clemson College, South Carolina, and given a year's leave of absence for graduate study at Iowa State College. R. W. Hamilton, Extension Agronomist, is acting Chief of the Agronomy Division for the year.

A new journal to be known as *Coton et Culture Cotonniere* has been started by the French Committee for the Encouragement of Scientific Colonial Research, and will be published in three or four numbers per year from the Paris headquarters of the Committee.

STANDING COMMITTEES FOR 1927

President W. L. Burlison has appointed the following members of the several committees of the Society for the coming year:

AGRONOMIC TERMINOLOGY

C. R. Ball (Chairman) Chas. F. Shaw H. L. Shantz

STANDARDIZATION OF FIELD EXPERIMENTS

S. C. Salmon (Chairman) T. A. Kiesselbach H. H. Love
M. M. McCool C. A. Mooers

VARIETAL STANDARDIZATION

H. H. Hayes (Chairman) L. H. Newman L. J. Stadler
T. R. Stanton R. G. Wiggans

SUBCOMMITTEES ON VARIETAL REGISTRATION

Barley

H. V. Harlan (Chairman) (1929) R. G. Wiggans (1928)
E. F. Gaines (1927)

Corn

F. D. Richey (Chairman) (1929) C. M. Woodworth (1927)
D. F. Jones (1928)

Oats

T. R. Stanton (Chairman) (1929) H. H. Love (1928)
E. E. Down (1927)

Wheat

J. Allen Clark (Chairman) (1929) L. R. Waldron (1928)
J. H. Parker (1927)

CROPS TEACHING METHODS

J. O. Morgan (Chairman) Clyde McKee J. B. Wentz

SOILS TEACHING METHODS

H. O. Buckman (Chairman) M. F. Miller H. L. Walster

INTERNATIONAL CONGRESS OF SOIL SCIENCE

J. G. Lipman (Chairman) C. F. Marbut A. G. McCall

COOPERATION WITH THE NATIONAL RESEARCH COUNCIL

R. A. Oakley (Chairman) (1929) C. W. Warburton (1927)
A. G. McCall (1928)
T. A. Kiesselbach (1930) J. G. Lipman (1931)

FERTILIZER DISTRIBUTING MACHINERY

S. B. Haskell (Chairman) J. R. Fain Emil Truog

CORN BORER INVESTIGATIONS

L. E. Call (Chairman) W. L. Burlison J. F. Cox
F. D. Richey R. M. Salter

Special Committee to Represent this Society at Sessions of the Society for Promotion of Agricultural Teaching

H. L. Walster H. D. Hughes

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